PROCEEDINGS

OF THE

PHYSICAL SOCIETY

OF LONDON.

VOL. 13. PART 10.

OFFICERS AND COUNCIL.

President.

CAPT. W. DE W. ABNEY, R.E., C.B., D.C.L., F.R.S.

Vice-Presidents who have filled the Office of President.

DR. J. H. GLADSTONE, F.R.S.
PROF. G. C. FOSTER, F.R.S.
PROF. W. G. ADAMS, M.A., F.R.S.
LORD KELVIN, D.C.L., LL.D., P.R.S.
PROF. R. B. CLIFTON, M.A., F.R.S.
PROF. A. W. REINOLD, M.A., F.R.S.
PROF. W. E. AYRTON, F.R.S.
PROF. G. F. FITZGERALD, M.A., F.R.S.
PROF. A. W. RÜCKER, M.A., F.R.S.

Vice-Presidents.

WALTER BAILY, M.A.
MAJ.-GEN. E. R. FESTING, R.E., F.R.S.
PROF. J. PERRY, D.Sc., F.R.S.
G. JOHNSTONE STONEY, M.A., F.R.S.

Secretaries.

T. H. BLAKESLEY, M.A., M.I.C.E.
H. M. ELDER, M.A.

Treasurer.

DR. E. ATKINSON.

Demonstrator and Librarian.

C. VERNON BOYS, F.R.S.

Other Members of the Council.

SHELFORD BIDWELL, M.A., LL.B., F.R.S.
PROF. W. CROOKES, F.R.S.
L. FLETCHER, M.A., F.R.S.
R. T. GLAZEBROOK, M.A., F.R.S.
G. GRIFFITH, M.A.
PROF. O. HENRICI, Ph.D., F.R.S.
PROF. G. M. MINCHIN, M.A.
JAMES SWINBURNE.
PROF. S. P. THOMPSON, D.Sc., F.R.S.
PROF. S. YOUNG, D.Sc., F.R.S.

Editor.

J. SWINBURNE.
66 *Victoria Street*, S.W.

Abstractors.

R. APPLEYARD.
E. H. BARTON, D.Sc.
R. E. BAYNES, M.A.
H. BORNS, Ph.D.
G. H. BRYAN, M.A., F.R.S.
S. H. BURBURY, M.A.
C. V. BURTON, D.Sc.
J. W. CAPSTICK, M.A., D.Sc.
A. DANIELL, M.A.
T. E. EWAN.
E. E. FOURNIER D'ALBE.
PROF. A. GRAY, M.A.
A. GRIFFITHS, B.Sc.
J. L. HOWARD, D.Sc.
PROF. D. E. JONES, B.Sc.
R. A. LEHFELDT, B.A., B.Sc.
T. PRESTON, M.A.
W. G. RHODES, M.Sc.
S. RIDEAL, D.Sc., F.I.C.
E. C. RIMINGTON.
J. W. RODGER.
G. F. C. SEARLE, M.A.
S. SKINNER, M.A.
W. E. SUMPNER, D.Sc.
F. T. TROUTON, D.Sc.
W. WATSON, B.Sc.
W. C. D. WHETHAM, M.A.
L. R. WILBERFORCE, M.A.

Reporter.

W. WATSON, B.Sc.

LONDON:

TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

Price to Non-Members, Two Shillings & Sixpence.

Page

XLIV. A Theory of the Synchronous Motor. By W. G. Rhodes, M.Sc. (*continued*) 510

XLV. On the Use of an Iodine Voltameter for the Measurement of Small Currents. By E. F. Herroun, F.I.C., Professor of Natural Philosophy, Queen's College, London 517

XLVI. On the Condensation and the Critical Phenomena of Mixtures of Ethane and Nitrous Oxide. By Dr. Kuenen 523

XLVII. An Electromagnetic Effect. By F. W. Bowden .. 549

XLVIII. The Electrical Properties of Selenium. By Shelford Bidwell, M.A., F.R.S. 552

NAME INDEX (Abstracts).

Aignan, 381.
Alexejeff, 391.
Arctowski, 391.
Becquerel, 371.
Berthelot, 393.
von Bezold, 389.
Birkeland, 382.
de Boisbaudran, 392.
Bolton, 391.
Boltzmann, 385.
Campanile, 381.
Chabot, 381.
Chauveau, 367.
Clark, 387.
Clausius, 365.
Daniell, 387.
Darzens, 377.
Delaunay, 364.
Deslandres, 371.
Duhamel, 381.
Dunstan, 388.
Étard, 391.
Francke, 387.
Glazebrook, 388.
Gouré de Villemontée, 387.
Gouy, 364, 387.
Guillaume, 380.
Guntz, 374.
Hall, 386.
von Helmholtz, 368, 377, 378, 383, 390.
Hopkinson, 389.
Houllevigue, 365.
Jaumann, 386, 388.
Kirchhoff, 383.
Krone, 372.
Lea, 372.
Limb, 387.
Lippmann, 371.
Lœwy, 363.
Lommel, 385.
Lovén, 387.
Lumière, 377.
Mack, 389.
Marey, 381.
Maurain, 387.
Maxwell, 368, 383.
Morris, 376.
Natterer, 380.
Neuhass, 377.
Ostwald, 388, 391.
Painlevé, 367.
Paschen, 393.
Piltschikoff, 388.
Poitevin, 371.
Poulton, 376.
Poynting, 382.
Puiseux, 363.
Raoult, 367.
Rayleigh, 387.
Reed, 392.
Reiff, 390.
Runge, 393.
Schiller, 383.
Schultz-Sellack, 371.
Seebeck, 371.
Sénarmont, 389.
Starkl, 389.
Swyngedauw, 386, 388.
Tchebishtcheff, 365.
de Tillo, 390.
Torres, 366.
Valenta, 377.
Villard, 363, 380.
Vogel, 378.
Watson, 365.
Wiedemann, 386.
Wiener, 371.
Wood, 376.
Young, 371, 377.
Zenker, 371, 377.

WILLIAMS AND NORGATE,

14 HENRIETTA STREET, COVENT GARDEN, LONDON;
20 SOUTH FREDERICK STREET, EDINBURGH;
AND 7 BROAD STREET, OXFORD,

PUBLISHERS AND IMPORTERS OF

FOREIGN SCIENTIFIC BOOKS.

Largest Stock of Foreign Works, especially in the Departments of Physics, Electricity, Microscopy, Optics, etc.

MOST RECENT IMPORTANT CONTINENTAL PUBLICATIONS.

Arens (Fr.). Die Erzeugung der Electricität. 6*d.*

Behrens (H.). Anleitung zur mikrochemischen Analyse. Mit einem Vorwort von Prof. S. Hoogewerff in Delft. 224 Seiten mit 92 Figuren in Text. 8vo. 6*s.* net.

Biedermann (W.). Elektrophysiologie. 1te Abtheilung. Mit 136 Abbildungen. 440 Seiten. 8vo. 9*s.* net.

Brunhes (B.). Cours élémentaire d'électricité. Paris, 1895. 8vo. Avec 137 fig. 4*s.* 6*d.* net.

Dammer (Dr. O.). Handbuch der chemischen Technologie. Unter Mitwirkung von Direktor Th. Beckert, Dr. Bender, Dr. Benedikt, Dr. Börnstein u. A. herausgegeben. 2ter Band. Mit 235 in den Text gedruckten Figuren. gr. 8vo. 20*s.* net.

Demarçay (E.). Spectres électriques. Paris, 1895. 4to. Atlas de 10 pl. 20*s.* net.

Dumont (G.) et **Baignères** (G.). Étude sur le transport de l'énergie à grande distance par l'électricité. Paris, 1895. 8vo. VI, 114 pp. Avec 77 fig. 5*s.* net.

Fleming (J. A.). Electrical Laboratory Notes and Forms, elementary and advanced. London, 1895. 8vo. 250 pp. 12*s.* 6*d.* net.

Frick (Dr. J.). Physikalische Technik speciell Anleitung zur Ausführung physikalischer Demonstrationen und zur Herstellung von physikalischen Demonstrations-Apparaten mit möglichst einfachen Mitteln. 6. Umgearbeitete und vermehrte Auflage. Von Dr. Otto Lehmann. Vol. II. Gr. 8vo. XXVI. u. 1054 Seiten. Mit 1016 eingedruckten Holstichen und 3 Tafeln. 20*s.* net.

Hospitalier (E.). Recette de l'électricien. Colligées et mises en ordre par E. Hospitalier. 3*s.* 6*d.* net.

Jahn (H). Grundriss der Electrochemie. Vienna. 8*s.* 6*d.* net.

Jahrbuch der Elektrochemie. Berichte über die Fortschritte des Jahres 1894.—Im wissenschaftlichen Theile bearbeitet von Dr. W. **Nernst**, im technischen Theile von Dr. W. **Borchers.** I. Jahrgang. 274 Seiten. gr. 8vo. 10*s.* net.

Klimpert (Richard). Wiederholungsbuch zum Studium der Allgemeinen Physik und elementaren Mechanik. Dresden, 1895. 8*s.* net.

Kolbe (Bruno). Einführung in die Electricitätslehre. Band II. Dynamische Elektricität. Mit 75 in den Text gedruckten Holzschnitten. 187 Seiten. 8vo. 3*s.* net.

Laffargue (J.). Les Applications mécaniques de l'énergie électrique. In-12, avec 320 fig. Paris. 2*s.* 6*d.* net.
Forme le No. 3 de la 'Bibliothèque électrotechnique.'

Lehmann (Dr. Otto). Elektricität und Licht. Einführung in die messende Elektricitätslehre und Photometrie. 7*s.* net.

Lüpke (Rbt.). Grundzüge der wissenschaftlichen Elektrochemie auf experimenteller Basis. Berlin, 1895. J. Springer. VIII, 150 pp. Mit 46 fig. 3*s.* net.

Oppenheimer (C.). Grundriss der organischen Chemie. Berlin, 1895. 8vo. VII, 130 pp. 2*s.* 6*d.* net.

Poincaré (H.). Cours de Physique mathématique. Théorie analytique de la propagation de la chaleur. Paris, 1895. 8vo. 316 pp. Avec fig. 8*s.* 6*d.* net.

Propaedeutik Physikalisch-chemische von Prof. Dr. **Griesbach.** Part I. 6*s.* net.

Schwartze (Th.). Die Lehre von der Elektricität und deren praktische Verwendung. Mit 153 in den Text gedruckten Abbildungen. 543 Seiten. 8vo. 10*s.* net.

Schwerebestimmungen Relative durch Pendelbeobachtungen. Ausgeführt durch die k. und k. Kriegs-Marine in den Jahren 1892–94. Herausgegeben vom k. und k. Reichs-Kriegsministerium (Marine-Section). Umfang: 39½ Bogen Lex.-8vo. (522 Seiten Tabellen und 5 Tafeln). Geh. 18*s.* 6*d.* net.

Vogel (Dr. Fr.). Theorie electrolytischer Vorgänge. Halle. 5*s.* net.

Weierstrass (K.). Mathematische Werke. Herausgegeben unter Mitwirkung einer von der königl. preussischen Akademie der Wissenschaften eingesetzten Commission. II. Bd. Abhandlungen II. Berlin, 1895. 4to. VI, 362 pp. 21*s.* net.

Zickler (Prof. Karl). Das Universal-Elektrodynamometer. Mit 8 in den Text gedruckten Figuren. 32 Seiten. 8vo. 1*s.* net.

CATALOGUES AND MONTHLY LISTS OF FOREIGN BOOKS ON APPLICATION.

PERIODICALS SUPPLIED WITH THE UTMOST REGULARITY AND AT VERY MODERATE TERMS.

CAMBRIDGE UNIVERSITY PRESS.

The Scientific Papers of the late Prof. J. Clerk Maxwell. Edited by W. D. NIVEN, M.A., formerly Fellow of Trinity College. In 2 vols. Royal 4to. £3 3*s.* net.

Mathematical and Physical Papers. By Lord KELVIN (Sir W. THOMSON), LL.D., D.C.L., F.R.S., Professor of Natural Philosophy in the University of Glasgow. Collected from different Scientific Periodicals from May 1841 to the present time. Demy 8vo. Vol. I., 18*s.* Vol. II., 15*s.* Vol. III., 18*s.*

Mathematical and Physical Papers. By Sir G. G. STOKES, Sc.D., LL.D., F.R.S., Lucasian Professor of Mathematics in the University of Cambridge. Reprinted from the Original Journals and Transactions, with Additional Notes by the Author. Demy 8vo. Vol. I., 15*s.* Vol. II., 15*s.* [*Vol. III. in the Press.*

A Treatise on Analytical Statics. By E. J. ROUTH, Sc.D., F.R.S., Fellow of the University of London, Honorary Fellow of Peterhouse, Cambridge. Demy 8vo. Vol. I., 14*s.* Vol. II., 10*s.*

A Treatise on the Mathematical Theory of Elasticity. By A. E. H. LOVE, M.A., Fellow of St. John's College, Cambridge. 2 Vols. Demy 8vo. Vol. I., 12*s.* Vol. II., 12*s.*

History of the Theory of Elasticity, and of the Strength of Materials, from GALILEI to the PRESENT TIME. By the late I. TODHUNTER, Sc.D., F.R.S. Edited and Completed by Prof. KARL PEARSON, M.A.

Vol. I. GALILEI to SAINT-VENANT, 1639–1850. Demy 8vo. 25*s.*
Vol. II. SAINT-VENANT to LORD KELVIN (Sir William Thomson). Demy 8vo, in 2 Parts. 30*s.*

Hydrodynamics. By HORACE LAMB, M.A., F.R.S., formerly Fellow of Trinity College, Cambridge, Professor of Mathematics in the Owens College, Manchester. Demy 8vo. 20*s.* net.

Extract from Preface.—"This book may be regarded as a second edition of a *Treatise on the Mathematical Theory of the Motion of Fluids*, published in 1879; but the additions and alterations are so extensive that it has been thought proper to make a change in the title."

Electricity and Magnetism. By J. J. THOMSON, M.A., Cavendish Professor of Experimental Physics in the University of Cambridge. Crown 8vo. [*In the Press.*

The Steam-Engine and other Heat Engines. By J. A. EWING, M.A., F.R.S., M.Inst.C.E., Professor of Mechanism and Applied Mechanics in the University of Cambridge. Demy 8vo, with Illustrations, 15*s.*

Engineering Record, New York.—"Prof. Ewing's treatise furnishes a valuable addition to the literature of heat engines. . . . The matter is presented in well selected and attractive language, and what would otherwise be dry reading is made unusually interesting . . . . On the whole, Prof. Ewing has brought out a treatise which is admirable, so far as its scope extends. Its applications are mainly on the lines of English practice, and naturally so; but its exposition of the principles of steam-working are sound, and they will prove of undoubted assistance to every engineering student, whether American or English."

A Treatise on Elementary Dynamics. By S. L. LONEY, M.A., Fellow of Sidney Sussex College. Second Edition, enlarged. Crown 8vo, 7*s.* 6*d.* Solutions to the Examples, 7*s.* 6*d.*

"This is one of the best and most complete treatises on elementary dynamics which have come before us for a long time. The principles of the subject are stated with great clearness, and the illustrative examples are very appropriate."—*Athenæum.*

A Treatise on Elementary Hydrostatics. By J. GREAVES, M.A., Fellow and Lecturer of Christ's College, Cambridge. Crown 8vo. 5*s.*

"A brief examination of this treatise is sufficient to allow us to form a favourable opinion of its contents. Nearly every proposition or description shows that the author is a thorough master of his subject, and, what is also of equal importance, can impart his knowledge to his readers in language both concise and fresh."—*Nature.*

CAMBRIDGE NATURAL SCIENCE MANUALS.

PHYSICAL SERIES.

General Editor—R. T. GLAZEBROOK, M.A., F.R.S., Fellow of Trinity College, Cambridge, Assistant Director of the Cavendish Laboratory.

Mechanics and Hydrostatics. An Elementary Text-book, Theoretical and Practical, for Colleges and Schools. By R. T. GLAZEBROOK, M.A., F.R.S. Crown 8vo.
Part I. DYNAMICS. 4*s.* Part II. STATICS. 3*s.* Part III. HYDROSTATICS (nearly ready).

Educational Review.—"In detail it is thoroughly sound and scientific. The work is the work of a teacher and a thinker, who has avoided no difficulty that the student ought to face, and has, at the same time, given him all the assistance that he has a right to expect. We hope, in the interests both of experimental and mathematical science, that the scheme of teaching therein described will be widely followed."

Heat and Light. By R. T. GLAZEBROOK, M.A., F.R.S. Crown 8vo. 5*s.*
And separately, HEAT, 3*s.*; LIGHT, 3*s.*

Nature.—"Teachers who require a book suitable for the class-room and the laboratory would do well to adopt Mr. Glazebrook's work."

London: C. J. CLAY & SONS,
Cambridge University Press Warehouse, Ave Maria Lane.

10. To find the characteristic of the motor at any given load we must eliminate θ and ϕ between the equations

$$\left.\begin{aligned} p &= ce\cos\phi, \\ \sin\theta &= \frac{S}{I}, \\ \text{and} \qquad E^2 &= e^2 + I^2c^2 + 2Ice\cos(\theta-\phi). \end{aligned}\right\}$$

The eliminant is

$$E^2 - e^2 - I^2c^2 - 2Rp = 2S\sqrt{c^2e^2 - p^2}, \quad . \quad . \quad . \quad (8)$$

which is the required general relation between e and c.

11. In the paper referred to above, Steinmetz calls equation (8) the Fundamental Equation of the Synchronous Motor: the equation is there developed and plotted; results are obtained directly from equation (8), but the development is so cumbrous that the writer thinks that his simple treatment may benefit those interested in the subject of Alternate Current Motors.

Discussion.

Prof. S. P. Thompson said that the mathematical part of the paper was much simpler than that in previous investigations on this subject, and the method of arriving at the results by rejecting imaginary roots of the equations was particularly neat and instructive. The part of the paper relating to armature reactions and phase relationships was quite new. Two results deserved special attention; first, that the maximum current of zero power was the same as if the circuit was non-inductive; second, that the maximum current at zero power was double the current corresponding to maximum output.

Mr. Blakesley said that the paper did not consider the stability of the system, and he thought some of the results corresponded to regions of instability.

XLIV. *A Theory of the Synchronous Motor.*

By W. G. RHODES, *M.Sc.**

[Continued from p. 509.]

Armature Reaction in a Single Phase Alternate Current Machine.

12. IN the foregoing analytical treatment the magnitudes only of θ, ϕ, and ψ are considered. We proceed to investigate the signs of these angles in order to determine the lags or leads of the E.M.F.'s over the current and to apply the results to find out whether the field excitation of generator and motor is strengthened or weakened by the reaction of the armature currents.

13. It will now be convenient to slightly alter the meanings of the symbols.

Let E = virtual value of generator E.M.F.
e = „ „ counter E.M.F. of motor (as before);
R = total resistance in circuit consisting of generator, motor, and line:
L = sum of coefficients of self-induction of generator and motor armatures; or, if the line possesses self-induction, the coefficient of self-induction of the whole circuit;
I = impedance of the complete circuit;
S = reactance of the complete circuit.

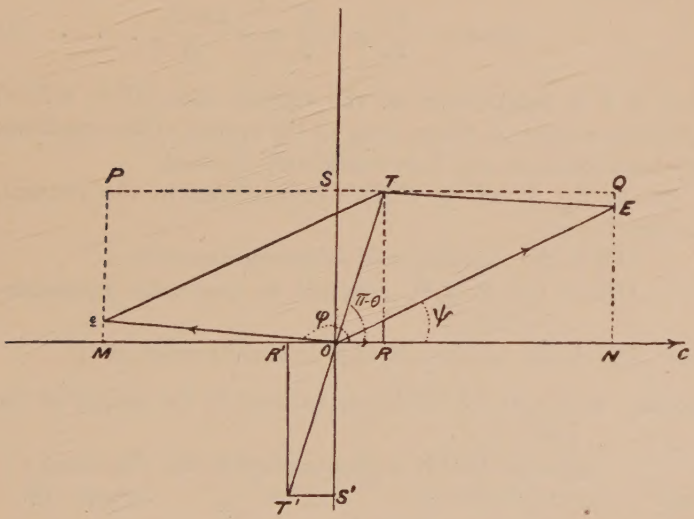
14. The E.M.F. Rc which drives the current is the resultant of E, e, and Sc; so that E, e, Sc, and Rc reversed form a system of E.M.F.'s in equilibrium.

In fig. 3 let the positive direction of rotation be counter-clockwise, and let Oc be the direction of the current. The instantaneous value of the current does not concern us at present. Take OR′ equal to Rc reversed, and consequently opposing the current; let OS′ = Sc, lagging behind the current by a quarter of a period. The resultant, OT′, of OR′ and OS′ will then be equal and opposite to the resultant of E and e. If,

* Read June 28, 1895.

therefore, we produce T′O to T and make OT = OT′, OT will represent in magnitude and direction the resultant of E and *e*. If, now, we are given the magnitudes of E and *e* we can find their directions by the parallelogram law. Now two parallelograms can be constructed having OT as diagonal and E, *e* as adjacent sides, but, since E is the E.M.F. of the generator, we take that which gives the component of E along

Fig. 3.



O*c* in the same sense as the current. The other parallelogram would make *e* the generator. We may notice that the possibility of constructing these two parallelograms affords a proof of the fact that, in general, either of two alternate current machines may be driven as a motor by the other, irrespective of their relative E.M.F.'s. An analytical proof of this is given by the energy equation

$$p + c^2R = cE \cos \psi,$$

remembering that

$$p = ce \cos \phi,$$

and that ϕ and ψ are independent.

The condition that E represents the generator E.M.F. limits our choice of the two parallelograms to OET*e* (fig. 3).

We then have

$$\text{angle } cOE = \psi,$$

$$\text{angle } cOT' = \theta,$$

and $$\text{angle } cOe = \phi.$$

15. Now through T draw PSTQ parallel to the line of current, and draw PM, SO, TR, and QN through e, O, T, and Q respectively, at right angles to the line of current.

We have

$$\tan\theta = -\frac{Sc}{Rc} = -\frac{S}{R} = -\frac{2\pi nL}{R}, \quad . \quad . \quad . \quad (9)$$

that is, θ is independent of the current and OT is a fixed direction relative to Oc so long as the speeds of the machines are kept constant, and L is considered constant.

16. In fig. 3, OS (or PM) is proportional to the current, $[=2\pi nLc]$;

OM is the component of e directly opposing c,

OR is the E.M.F. required to overcome resistance, $[=Rc]$;

and ON is the component of E in the direction of c;

hence, rectangle PSOM is proportional to the output of the motor $[p]$;

rectangle OSTR is proportional to the c^2R losses;

and rectangle OSQN „ „ output of generator $[cE\cos\psi]$.

From this, and the equation

$$p + c^2R = cE\cos\psi,$$

it follows that the efficiency of transformation

$$= \frac{OM}{ON} = \frac{OM}{MR}.$$

17. If the output of the motor is kept constant, we have

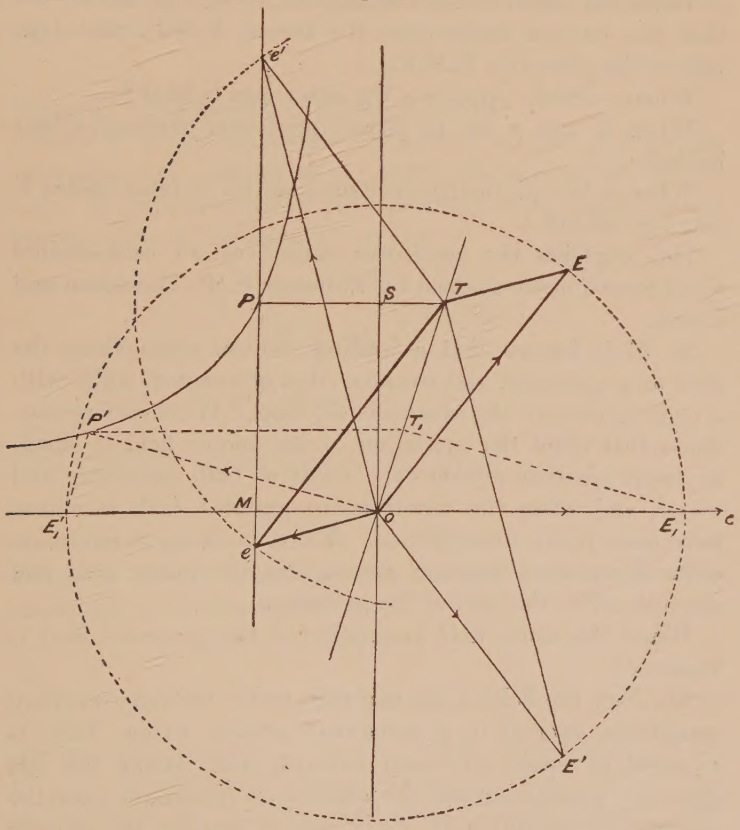
$$\text{rectangle PSOM} = \text{constant},$$

and the locus of P is a rectangular hyperbola having OM and OS as asymptotes (fig. 4).

Take any point P on this hyperbola. We have seen (9) that OT has a fixed direction relative to Oc; and the point T

(fig. 3) on this direction is found by drawing through P a line parallel to Oc. Again, e lies on the line through P parallel to OS and eT = E, in magnitude. Let the E.M.F. of the generator be kept constant and equal to E. With centre T and radius E describe a circle cutting PM in e and e'; then the corresponding counter E.M.F. of the motor may be

Fig. 4.



either Oe or Oe', and the current is represented in magnitude by PM: that is corresponding to given values of E and c there are two values of e. The relative phases in the two cases are shown in the parallelograms OeTE and Oe'TE' (fig. 4).

18. To find the point P' on the hyperbola corresponding to

minimum current we have to bring the points e and e' into coincidence. The point P′ is obviously got by taking OE_1' equal to E and through E_1' drawing $E_1'P$ parallel to OT. The resulting parallelogram $OP'T_1E_1$ shows that the generator E.M.F. is in phase with the current.

19. Suppose now that the excitation of the generator field is kept constant while that of the motor is varied.

When the motor excitation is small, as Oe (fig. 4), we see that the current leads over the motor E.M.F. and lags behind the generator E.M.F.

When e exactly opposes c, the latter lags behind E.

When E and c are in phase (minimum current), c lags behind e.

When e is still further increased, as Oe', c leads before E and lags behind e.

This explains the condenser action of an over-excited synchronous motor noticed by Professor S. P. Thompson and others.

20. It is known that a leading current strengthens the field of a generator and weakens that of a motor, while with a lagging current the reverse is the case. We therefore conclude that when the excitation of the motor field is small, armature reaction weakens the fields of both generator and motor, and when the motor is over-excited both machines have their fields strengthened. When working at minimum current, armature reaction strengthens the motor field and does not affect the field of the generator.

When the motor field is unaffected, the generator field is weakened.

21. Now the field of the motor is, under ordinary working conditions, excited to a somewhat greater extent than is required to obtain minimum current; for, though the c^2R losses are a minimum and the efficiency a maximum when the current is a minimum, it is advisable to increase the counter E.M.F. to a certain extent in order to cope with accidental variations of the load. Under ordinary working conditions, therefore, the effect of armature reaction is to strengthen the field of the motor and also of the generator, but to a less extent.

22. We now proceed to obtain an expression for the altera-

tion, in ampere turns, of the field excitation due to armature reaction.

Let ϕ be the displacement of phase of the current over the E.M.F. of the machine; n the number of turns of wire in one section of the armature; i the virtual current, and $i_0 \sin pt$ the instantaneous value of the current, so that i_0 is its maximum value.

It has hitherto been customary to assume that the alteration in the excitation is given by the expression

$$in\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where ϕ is expressed in circular measure.

Now it is not the *virtual* current to which the armature reaction is due, but the *mean value of the current* through an angle ϕ on each side of its maximum value; that is, the proper value of the current is given by

$$\mathrm{I} = \frac{p}{2\phi} \int_{\left(\frac{\pi}{2}-\phi\right)\frac{1}{p}}^{\left(\frac{\pi}{2}+\phi\right)\frac{1}{p}} i_0 \sin pt \, dt$$

$$= \frac{i_0}{\phi} \sin \phi.$$

And, remembering that $i_0 = \sqrt{2} \, . \, i$, we get

$$\mathrm{I} = \frac{\sqrt{2} \, . \, i}{\phi} \sin \phi.$$

Thus the proper expression for the alteration of the field excitation in ampere turns is

$$2\mathrm{I}n\phi$$

or

$$2\sqrt{2}in \sin \phi. \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

To find the total excitation of the field we must add expression (11) to or subtract it from the ampere turns on the field according as the current leads or lags in a generator, and lags or leads in a motor.

Discussion.

Mr. Tunzelmann expressed a hope that the author would amplify parts of his paper.

Mr. Blakesley said the conclusion of the author, that

"either of two alternate current machines may be driven as a motor by the other, irrespective of their relative E.M.F.'s," is not invariably correct. The facts of the case were these:—The E.M.F. of the motor may exceed that of the other machine to a certain extent; but that E.M.F. multiplied by the cosine of the angle of electric lag must yield a product not greater than the E.M.F. of the generator,—*i. e.*, using Mr. Rhodes's symbols, $e \cos \theta$ must not be greater than E. Mr. Blakesley gave a geometrical proof of this; but the same proposition had been given by him some ten years ago, in the course of investigating the subject generally. This was at a time when Dr. John Hopkinson was, with less than his usual perspicuity, teaching that synchronous alternate current machines could not be run in series with stability, both doing work. Referring to the author's diagrams, Mr. Blakesley said that in a problem involving so many elements as that under consideration, it was impossible, with the limited dimensions of space, to represent the results with the complete generality of a formula. Some elements had to be taken as the independent, others as the dependent, variables. The author had considered the power transmitted to the motor, the E.M.F. of the generator, and the angle of electric lag, as independent; the E.M.F. of the motor as dependent. In Mr. Blakesley's original diagrams the E.M.F.'s were both considered independent, as well as the electric lag, and the powers applied or transmitted as dependent variables. In any case the formulæ properly derived from such diagrams became perfectly general, and it did not appear to him that the change of method indicated could properly be called a new theory on the subject. As a matter of fact, diagrams based on the independence of the E.M.F.'s and the electric lag would furnish a better means of discussing the question of the stability of the motion than Mr. Rhodes's plan, and this might account for the entire omission from the paper of this important matter.

Prof. S. P. Thompson said it was impossible to discuss the question of stability till the subject of armature reaction had been thoroughly investigated. The terms lag and lead had been used by Mr. Rhodes in a consistent manner; but this was not always done, and he recommended that the phase of

the current which was common to both generator and motor be taken as the standard.

The Author, in his reply, said he agreed with Mr. Blakesley that there was a limit to the extent to which the motor might be excited, and this upper limit could easily be obtained from the figure given in the paper. The question of armature reaction was, however, most important, as it might excite the field two or three times more than the original excitation. Since motors were designed to do a certain amount of work, and not the work to fit the motor, it was most natural to take the output of the motor as fixed.

XLV. *On the Use of an Iodine Voltameter for the Measurement of Small Currents.* *By* E. F. Herroun, *F.I.C., Professor of Natural Philosophy, Queen's College, London**.

The instruments in general use for the direct measurement of currents by electrolysis, as in the determination of reduction factors of galvanometers, comprise the hydrogen, silver, and copper voltameters: each of these possesses certain advantages, but none is free from defect. When occasion arises to make a large number of determinations of relatively small currents, the difficulties attending their use become more manifest.

Some of the defects of the ordinary types may be briefly stated. The hydrogen voltameter, consisting of platinum plates immersed in dilute sulphuric acid, has the following disadvantages:—

1. It acquires a large counter electromotive force of polarization, so that the current, on first joining up, is very inconstant.

2. Its internal resistance is subject to considerable fluctuations, according to the rate and mode of disengagement of the electrolytic gases.

3. Oxygen present in the dilute acid, or migrating from

* Read May 10, 1895.

the anode, diminishes the amount of hydrogen collected, and so causes the current to be underestimated.

4. When small currents are being measured, the bubbles which cling to the electrodes or sides of the graduated tube cause an appreciable error.

5. Calculation of the current-strength is rendered difficult owing to the necessity for correcting the volume of gas for temperature, barometric pressure, and for the tension of vapour of the dilute acid employed, which last is frequently not exactly known.

In the silver voltameter the foregoing objections do not hold, with the exception of No. 3 ; for dissolved oxygen has been found to affect the yield of silver, a greater amount being obtained when the electrolysis is conducted *in vacuo* or hydrogen than in air. But in the silver voltameter the experimental difficulties in washing, drying, and weighing, it may be only a few centigrammes of silver, involve a large expenditure of time ; or if the weight of deposited silver be increased by prolonging the current, the difficulty of maintaining it constant is greater.

The difficulties which exist with silver are still more apparent with copper ; for, as its chemical equivalent is much smaller, the weight of copper yielded by a given number of coulombs is only $\frac{31{\cdot}75}{108}$ of the weight of silver. In addition, its greater readiness to oxidize may cause the deposit of copper to become superficially oxidized in the process of washing and drying. This, however, may partly compensate for the defect in weight due to dissolved oxygen round the kathode.

If a list of the electrochemical equivalents of elements be examined, next to mercur*ous* mercury, the one which has the highest value will be found to be iodine ; and it is curious that, although the liberation of iodine from potassic iodide was very early used to detect electric currents, no attempt in recent years seems to have been made to utilize it for quantitative measurements.

As iodine is an anion, dissolved oxygen, which diminishes the yield at the kathode in other voltameters, will have no such action in a neutral solution of iodide ; and as its colour

reaction with starch is extremely sharp, and its titration with standard sodium thiosulphate a process of greater accuracy than the performance of the average balance, the exact determination of the amount of iodine liberated by a current is both easy and rapid.

Experimental Details.

A voltameter consisting of platinum plates in a solution of potassic iodide is not suited for quantitative measurement; as, upon electrolysis, it yields caustic potash and hydrogen at the kathode, the former of which by diffusion would come in contact with the iodine set free at the anode, converting it into iodide and iodate. If this were all it would be easy to acidify after electrolysis, when the iodine would be again set free; but there is besides the additional disadvantage, that a rather large electromotive force of polarization is set up between the electrode surrounded by hydrogen and KOH and the one surrounded by iodine.

The solution actually employed was a 10 per cent. to 15 per cent. solution of neutral zinc iodide (a solution that keeps well if a small strip of zinc be suspended in it). The anode was a plate or disk of platinum placed at the bottom of a tall narrow beaker and joined by a platinum wire, sealed through a glass tube extending beyond the top of the beaker, to the outside circuit. In this way all the iodine is liberated at the bottom of the column of liquid, and, owing to its high density, tends very little to diffuse upward. The kathode was a rod of amalgamated zinc, loosely jacketed with filter-paper or linen. The zinc rod should be supported so that it only dips a few centimetres into the top of the liquid, thus diminishing the liability of any of the liberated iodine coming in contact with it. The jacketing was found necessary to prevent particles of electro-deposited zinc becoming detached and falling into the solution of iodine at the bottom of the cell.

When used with currents not exceeding $\frac{1}{20}$ of an ampere and an anode of 9 square centimetres, it was found that no iodine diffused up to the level of the kathode in experiments of over an hour's duration, the cell being kept completely at rest. With feebler currents, lasting for a protracted time, it was found advisable to use a U-tube with a good plug of

asbestos in the bend, filled with the zinc-iodide solution and having a platinum plate and zinc rod in the two sides of the tube ; but naturally with this form the resistance was much greater than with the beaker form.

With large currents "electric convection" leads to diffusion of the iodine through the whole liquid, and therefore the author does not consider it well adapted for their measurement, except for approximate, rapid determinations.

In the Report to the Board of Trade of the Electrical Standards Committee, the importance is pointed out, in using a silver voltameter, of having a considerable *wire*-resistance in the circuit to mitigate the effect of change of resistance in the voltameter itself: the same precautions apply to the iodine voltameter and a slight readjustment of the resistance at first employed is usually necessary to keep the current, as indicated by a galvanometer, constant. This is owing to a small change in the adverse electromotive force, but if a battery of fairly high E.M.F. (*ex. gr.* 3 Grove cells) be employed, controlled by a moderately large resistance, the current may be kept very constant.

After the iodine voltameter has been in circuit for a time which will vary with the degree of accuracy required and the actual strength of the current, the latter is stopped and the zinc kathode is immediately removed from the liquid. The solution is then stirred up, and the amount of free iodine determined by direct titration with standard sodium thiosulphate solution, after the addition of starch. Taking the electrochemical equivalent of iodine as ·001314 grm. per coulomb, a convenient strength of sodium thiosulphate solution is one of which each cubic centimetre reduces five times this amount (1 cub. centim. = ·00657 grm. I): this corresponds to a solution containing 12·845 grms. of pure sodium thiosulphate per litre; but it is necessary to standardize it from time to time with a standard solution of iodine, as its value is liable to change somewhat on keeping.

As pure zinc iodide is not always readily obtainable, though it can be easily prepared, the author has found that a solution of 15 per cent. zinc chloride, to which about 5 per cent. potassic iodide has been added, may be substituted for pure

zinc iodide. Any chlorine, even if liberated, which is improbable with small current-densities, would at once yield its equivalent in iodine without escaping, and should any caustic potash form at the kathode it would merely produce zinc hydrate and potassic chloride.

A single example of the accuracy and rapidity of the method, selected from laboratory notes, may here be given :—

" Dec. 19, 1894.—Current through calibrated galvanometer $=20°$.

Time current was passing = 2 hours.
Weight of silver deposited = 0·2122 grm.
Current (from above deposit) = 0·0264 ampere.

The same deflexion (20°) obtained using iodine voltameter.

Time = 30 minutes.

Iodine liberated required 9·6 cub. centim. of standard thiosulphate sol. $9{\cdot}6 \times 5 = 48$ coulombs. Current $= \frac{48}{1800^s} = 0{\cdot}0266$ amp."

The latter result is seen to be in fairly close agreement with that obtained with the silver voltameter, but slightly higher, as was to be expected from the reasons stated above. It will be noticed that the duration of the experiment was only a quarter of that with the silver voltameter.

In conclusion the points which recommend the iodine voltameter in the author's opinion are as follows :—

1. Its freedom from the effect of dissolved oxygen which gives " low " results with kationic voltameters.

2. The relatively short duration of the current necessary to obtain results of fair accuracy.

3. The rapidity of the volumetric estimation of the liberated iodine.

4. The ease and rapidity in calculating the results.

Discussion.

Prof. Carey Foster considered this process for measuring currents a most valuable one. The idea of using a volumetric method for measuring currents was, to him, new. He did not, however, see the advantage of using a substance

with a high electro-chemical equivalent if a volumetric method was employed to estimate the quantity of the substance liberated. It would be possible to use a chloride, though in this case the titration would probably be less accurate.

Prof. SILVANUS THOMPSON said he thought the method would be very valuable, but he would like to know if any error was likely to arise if too great a current density was employed. The number the author had assumed for the atomic weight of silver (108) was only approximate; if the more accurate value 107·7 were used the agreement between the results obtained with the silver and iodine voltameters would be improved.

Mr. TROTTER asked what was the largest current that could be accurately measured.

Mr. ENRIGHT said he had used porous diaphragms in iodine voltameters, and found that the iodine collected in the positive compartment, while the water was driven over into the negative compartment. With strong currents it was possible to get almost pure iodine left in the one compartment.

Mr. WATSON thought that since the value for the electro-chemical equivalent of iodine used by the author was deduced from Rayleigh's value of the electro-chemical equivalent of silver, and that Rayleigh's experiments were performed in air, the difference obtained with the silver and iodine voltameters could hardly be due to the cause suggested.

Mr. ELDER warned the members that volumetric measurements were not so accurate or easy as they seemed. He particularly mistrusted a solution of sodium thiosulphate, since he had found a solution of this substance to change even in twenty-four hours. The difficulty of accurately reading the burette might be overcome by weighing the burette and its contents before and after the titration.

The Author, in his reply, said that with the size of electrodes he used (about 9 sq. cm. surface), 0·1 ampère was the maximum current it was safe to use. The only substance likely to be produced by too great a current density was periodate, which, since it was insoluble, would immediately be noticed. The influence of the dissolved oxygen was only

appreciable with small currents where the electrolysis lasts some time ; while in Rayleigh's experiments large currents were employed.

The CHAIRMAN, while returning thanks to the author for the paper, mentioned that in his experience he had found zinc salts to be very untrustworthy.

XLVI. *On the Condensation and the Critical Phenomena of Mixtures of Ethane and Nitrous Oxide.* *By* Dr. KUENEN*.

1. BEFORE relating the results arrived at in this investigation I shall have to give a short account of the course of thought which led to the choice of the subject.

My experiments on the conduct of mixtures† are based upon the theory of Prof. van der Waals‡. Van der Waals "describes" the properties of mixtures by means of an isothermal surface, the coordinates of which are the composition of the mixture x $(0<x<1)$, the volume v, and the free energy ψ ($\psi=\epsilon-t\eta$; $\epsilon=$ energy, $\eta=$ entropy, $t=$ temperature). On this surface there appear *plaits*§, which determine the coexistence of two or more phases. Those points of these plaits which have a common tangent plane represent the phases which may coexist at the temperature for which the surface is constructed, and at a pressure indicated by the slope of the tangent plane $\left(p=-\frac{\partial\psi}{\partial v}\right)$. The double curves traced out by rolling the tangent planes over the plaits are the so-called *connodal* curves. It may happen that the plaits terminate on the surface itself (*i. e.* between the planes for which $x=0$ and $x=1$). In that case the coexisting phases approach each

* Read May 24, 1895.

† Kuenen, *Archives Néerl.* xxvi. pp. 354–422; *Zeitschr. phys. Chemie*, xi. pp. 38–48; *Verhand. Kon. Akad. Amsterdam*, passim; Communications from the Labor. of Physics, Leiden, Nos. 4, 7, 13.

‡ Van der Waals, *Archives Néerl.* xxiv. pp. 1–56; *Zeitschr. phys. Chemie*, v. pp. 133–173.

§ For the nomenclature used in this treatise, *cf.* Korteweg, *Wien. Ber.* xcviii. pp. 1154–1191; *Archives Néerl.* xxiv. pp. 57–98.

other and at last coincide in a so-called *plaitpoint*. In studying the plaits on the surface, one may use the projection upon the x–v plane. This projection consists of the x-axis between $x=0$ and $x=1$, the two v-axes for $x=0$ and $x=1$, the connodal curves with or without the plaitpoints. The points of the connodal curves belonging together may be joined by straight lines. The ratio of the parts into which these lines are divided by a line perpendicular to the x-axis, say for $x=x_1$, represents the ratio of the quantities of the two phases which will be formed when the mixture x_1 is taken at the pressure at which the two phases may coexist. Keeping this in view, it is easy to derive the condensation and critical phenomena of a mixture.

2. We shall only discuss the very simple case here, that there is only one plait on the surface, the vapour-liquid plait, which determines the coexistence of a vapour-phase and a liquid-phase. The plait, roughly speaking, has the direction of the x-axis; its plaitpoint, which will make its appearance if only we raise the temperature to a sufficient height, need not coincide with the end of the plait, *i. e.* with that point of the connodal curve which is nearest to one of the ψv planes (in the projection $= v$-axis). The latter point was called *critical point of contact**. Now in deriving the critical phenomena two cases have to be distinguished depending on the relative position of these two points, which we shall call P and R. Either P is situated nearer to the ψx plane (x-axis) or this is the case with R.

3. In the first case the condensation of a mixture has the following character. Below a definite temperature (plaitpoint-temperature $= T_P$), different for every mixture, the quantity of the denser phase increases regularly during compression; the pressure rises, and both the composition and the volume of both phases change continuously. Above another temperature (temperature of the critical point of contact = critical temperature $= T^R$) there is no condensation possible. At temperatures ranging between T_P and T_R the condensation will have the following character:—With compression the

* Kuenen, *Archives Néerl.* xxvi. p. 379; Communications from the Lab. of Physics, Leiden, No. 4, pp. 7 *sqq.*; *Zeitschrift phys. Chemie*, xi. p. 44.

quantity of the appearing liquid first increases, reaches a maximum value, and after that decreases till it disappears. This was called *retrograde condensation of the first kind* (r.c. I.)*. The nearer we get to the plaitpoint-temperature the larger becomes the quantity of the liquid and the smaller the difference between the phases, apparent from a less distinct liquid surface between the phases. A mixture, therefore, has a critical region instead of one critical point, lying between two critical temperatures.

4. The phenomena predicted in this manner were then observed by me in mixtures of carbonic acid and methyl chloride†, and afterwards of carbonic acid and air‡. The deviation from what had been observed by former experimenters, viz., the flattening and disappearing of the liquid surface throughout the critical region without retrograde condensation, was explained by retardation§, which was annihilated in my experiments for the first time by means of a small iron stirring-rod within the tubes, which was moved by an electromagnet outside the tubes.

5. If P lies on the other side of R there are again two definite critical temperatures, T^P and T_R, for every mixture; but the process of condensation between those two will be different from what it was in the first case. By compression a new phase appears of a larger volume‖ this time, *i. e.* a vapour-phase, which begins by increasing, then reaches a maximum, and then again diminishes and disappears. This was called *retrograde condensation of the second kind* (r.c. II.)¶. Near the plaitpoint-temperature T_P the liquid

* Kuenen, *Archives Néerl.* xxvi. pp. 378–379; Commun. No. 4; *Zeitschr. phys. Chemie*, xi. p. 44.

† Kuenen, *Archives Néerl.* xxvi. pp. 382–385; Commun. No. 4; *Zeitschr. phys. Chemie*, xi. p. 47.

‡ Commun. No. 7, p. 6.

§ Kuenen, *Archives Néerl.* xxvi. pp. 376–377, 380–382; Commun. No. 4; *Zeitschr. phys. Chemie*, xi. p. 47.

‖ In order to make the volumes in our figures decide about the situation of the phases above each other, we should take the volume of the unit of weight as the unit of volume. In doing so a phase of larger volume is a lighter phase at the same time, and will therefore appear in the upper part of the tube.

¶ Kuenen, *Archives Néerl.* xxvi. pp. 388–389; *Zeitschr. phys. Chemie*, xi. p. 45.

will be very flat and indistinct, and more so at the beginning than near the end of the condensation. Below T_P the condensation is normal.

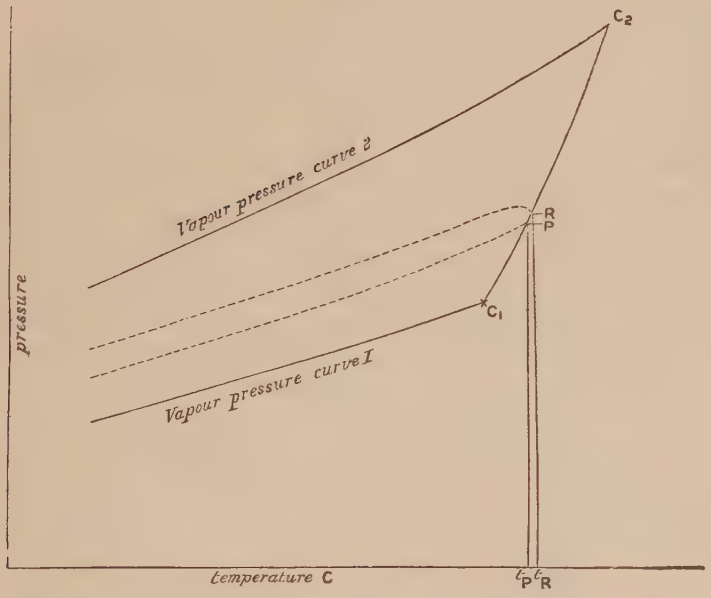
6. This second case has never been realized till now. I have been considering whether it might be, and the choice of the subject of this paper is the outcome of my reasoning. In explaining this I shall use a different graphical representation, namely the p–t figure. In a recent paper * I have deduced the general features of the p–t curves in the problem before us from van der Waals's theory. The figure obtained consists of (1) the two *vapour-pressure curves* of the component substances; (2) the *border-curves* † for the mixtures (x = constant) having the form of loops; (3) the *plaitpoint-curve*, being the envelope of the border-curves and connecting the critical points of the two substances. The point of contact between a border-curve and the plaitpoint-curve corresponds to the plaitpoint P of van der Waals's surface; the critical point of contact R is the point in which the border-curve has a tangent parallel to the p-axis. When going along the border-curve, starting from its lower branch, we may either first reach R or P. These two cases correspond to the two cases mentioned above. If P is situated beyond R we have r.c. I. (figs. 8, 9); if R lies beyond P we have r.c. II. (fig. 10). Keeping in view the connexion between border-curve and plaitpoint-curve, the question whether the second case can be realized comes to the same as whether the plaitpoint-curve or a part of it may rise, while the border-curves are situated on its left side (fig. 10). Now it appears that there are different cases in which such a situation must occur. If the critical points of some of the mixtures lie outside the critical temperatures of the two substances, a part of the plaitpoint-curve will answer to the above postulate. But this is not a necessary condition. If the substance of the higher critical temperature has at the same time larger vapour-pressures than the substance of the lower critical temperature, the plaitpoint-curve will have the same property. This case

* Kuenen, *Kon. Akad. Amsterdam*, 29 Sept. 1894, pp. 90–99; 'Communications,' &c. No. 13.

† A border-curve for a mixture represents the conditions (p, t) in which it may coexist with a second phase.

is represented in fig. 1. R lies beyond P. Between the two temperatures T_P and T_R the mixture, the border-curve of which is drawn in the figure, must show retrograde condensation of the 2nd kind (r.c. II.). Even if the curves are more complicated than is supposed in the figure, the curve $C_1 C_2$ will nevertheless fulfil the condition at least for a part of its course.

Fig. 1.



7. There is only a small number of combinations of two substances which appear to answer the purpose. Substances of low critical temperatures mostly have high critical pressures and high vapour-pressures. When this is not so, the differences are often too small to promise striking results. My attention was at last drawn to *ethane*, a substance of low critical pressure ($\pm$50 atm.) and a critical temperature of $\pm$34° C. Combinations of this substance with HCl, C_2H_2, N_2O, especially the last, promised good results.

For this combination I expected to find a case such as is represented in fig. 1. It will appear that my expectation has been surpassed in so far as these mixtures happen to offer some

interesting properties which had never been observed and require a more complex representation than fig. 1. At the same time the phenomenon (r. c. II.), to find which was the starting-point of the investigation, has escaped observation till now.

Preparation of Ethane (C_2H_6).

8. The ethane was prepared by electrolysis of a concentrated solution of acetate of sodium. By this process a number of other substances are generated, especially CO_2, O_2, C_2H_4, and some esters*. The gas was washed in sulphuric acid and a solution of caustic soda, and collected in a big glass bottle (45 litres) again containing a solution of caustic soda. In this manner the CO_2 was absorbed entirely. By aid of a mercury compressing machine of Cailletet, which belongs to the set of apparatus of the Leiden Laboratory for experiments at low temperatures, the ethane was liquefied in a small copper vessel. In this operation it passed again through fuming sulphuric acid, caustic potash, and phosphoric anhydride. In order to expel the permanent gases, the liquid ethane was cooled by solid carbonic acid and made to boil. In filling the tubes the gas was afterwards taken from the liquid.

This method of purification at low temperature has been formerly applied by me to CO_2 and CH_3Cl†.

Preparation of Nitrous Oxide (N_2O).

9. This substance was taken from a commercial bottle; it was led through high-pressure tubes containing chloride of calcium and caustic potash and afterwards dried over P_2O_5. The purification was conducted as in the former case. During the boiling of the liquid N_2O the tube could be connected with an air-pump, a sort of mercury-valve being interposed in order to prevent air from returning to the liquid.

* Kolbe, *Lieb. Ann.* lxix. p. 279; Wiedemann, *Electricität*, ii. p. 574.

† Kuenen, *Archives Néerl.* xxvi. pp. 356, 359. Olszewski was the first to apply this method of purifying gaseous substances so far as I know.

Preparation of the Mixtures.

10. The substances thus purified could be mixed in any proportion by means of my mixing apparatus, for the description of which I refer to previous investigations*. At present the whole apparatus consists of glass and copper only: the exhaustion was effected by a mercury air-pump.

Method of the Observations.

11. For the observations I made use of Ducretet's apparatus†. The glass tubes in which the gases were to be compressed were connected with the above apparatus by means of ground joints, and repeatedly exhausted and filled with the gases.

12. The temperatures, all of them ranging between 0° and 40° C., were obtained by means of a continuous current of water through a tube surrounding the experimental tubes.

13. My stirring apparatus‡, which was continually used during the observations, had been slightly modified. The little piece of iron with its knobs of enamel within the high-pressure tubes was the same as before; but the electromagnet, which used to slide over the tube and accordingly within the water-vessel, had been replaced by a larger bobbin sliding over the outside of the water-vessel. In this manner the influence of the temperature of the bobbin upon the temperature of the water, the constancy of which used to be disturbed during the acting of the apparatus, was removed. The bobbin is worked by four Bunsen cells or two accumulators.

Results obtained with Ethane.

14. In order to test the purity of the substances they were at first investigated separately. The gases appeared still to contain a little impurity: there was a slight increase of pressure during the process of condensation, for the ethane at 20°, 0·56 atmosphere. The amount of impurity of a gas corresponding to a definite increase of pressure at a definite temperature is difficult to decide, and entirely depends upon the substance itself and the admixture. In preparing the gas

* Kuenen, *l. c.* p. 369. † *L. c.* pp. 357, 366. ‡ *L. c.* pp. 372 *sqq.*

a second time, the liquid ethane was cooled in liquid ethylene boiling at a low pressure (−110° C.), itself being connected with an air-pump as in the case of nitrous oxide. The ethane obtained in this manner was found to be a little purer still: the increase of pressure was 0·43 atm. at the same temperature*.

15. The critical temperature of the gases was determined very carefully: as with the mixtures, a stirring-rod had been put within the tube, and so the determination could be conducted according to the principles explained in the account of my observations with CO_2†. The critical temperature for the two samples of ethane amounted to 31°·95 C. and 32°·05 C. respectively. This would point to a critical temperature of $\pm 32°{\cdot}3$ for pure ethane. By admitting a little air ($\frac{1}{4}$ to $\frac{1}{2}$ per cent.) into the last tube the increase of pressure at 20° C. rose to 2·7 atm., *i. e.* more than six times the former value; while the critical temperature had gone down to 31°·25 C. This would point to $\pm 32°{\cdot}2$ C. as the real critical temperature of ethane. The admixture in my ethane seems to lie far below 0·1 per cent.

16. It is not impossible that, in filling the tubes, a little air remains in the gases, because they have to pass through some long tubes connected with joints before entering the experimental tube, and the air has to be expelled by means of exhaustion. I might probably have got a still purer gas by filling the tube more directly, but I preferred to apply exactly the same method which I used in preparing the mixtures, in order to be warranted against mistakes resulting from differences of purity.

17. The critical temperature of ethane as determined by former observers is somewhat higher. Dewar‡ gives 35° C., Olszewski§ 34° C., Haenlen‖ from 32° C. to 40° C., probably

* Andrews, in his famous experiments on carbonic acid, observed an increase of pressure of more than two atmospheres in a similar case.

† Kuenen, *Kon. Akad. Amsterdam*, 29 Oct. 1893, pp. 85–90; Communications, &c., No. 8, pp. 11, 12.

‡ Dewar, Phil. Mag. [5] xviii. p. 214.

§ Olszewski, *Bulletin Ac. des Sciences de Cracovie*, 1889, p. 27.

‖ Haenlen, *Lieb. Ann.* cclxxxii. p. 245.

34°·5 C. In his experiments retardation has played an important part, and his gas cannot have been very pure; otherwise one finds a definite critical point, not a critical region as he does. He prepared the gas by the method of Gladstone, Tribe, and Frankland* from C_2H_5I. Olszewski obtained ethane from C_2H_5Zn. Both Haenlen and Olszewski purified the gas by cooling and boiling at a low temperature.

I cannot tell what the reason is of this discordance between the values for the critical temperature. Perhaps it has some connexion with the different ways of preparing the gas. I am going to repeat the experiments with ethane prepared from C_2H_5I. But the difference may be due to the method of determining the critical state as well. In my experiments the retardation is entirely annihilated by carefully stirring the gas, which may have lowered the critical temperature.

Results obtained with Nitrous Oxide.

18. Similar results were obtained with this gas. The increase of pressure, however, was still less. At 20° C. it amounted to 0·15 atm. = 11 cm. of mercury. The impurity of the gas may be estimated below 0·0002: for the critical temperature I obtained 35°·95 and 36°·05. The true value will be 36°·1 C. probably.

19. Villard, who has prepared pure nitrous oxide by a similar process†, fixes the critical temperature of his gas at 38°·8 C. But this value was obtained by the indirect method

* J. Chem. Soc. xlv. p. 154; xlvii. p. 236.

† Villard, *C. R.* cxviii. p. 1096; *Journal de Phys.* [3] iii. Oct. 1894. In a letter Dr. Villard tells me that his estimation of the critical temperature has been too high. In turning a tube with N_2O at 36°·5 C., the liquid surface disappeared and the tube filled itself with a blue mist. Now as stirring comes to the same as repeated turning, it is quite natural that I obtained a value for the critical temperature below 36°·5 C. I have not noticed the blue mist more than 0°·2 or 0°·3 above 36°·0 C. At any rate the disagreement between Villard's result and mine has been reduced to a few tenths of a degree. But it appears from Villard's measurements of the densities of N_2O, that the behaviour of this substance near its critical point is less normal, so to speak, than the behaviour of carbonic acid. One feels inclined to ascribe this to the influence of minute impurities.

of measuring the densities. The liquid surface disappeared below 38° C., but he does not mention an exact value. This gas must have been very pure, judging from the regular phenomena obtained near the critical point, and the purity of the carbonic acid prepared in the same manner. Villard states that in a U-tube in which two quantities of liquid N_2O were separated by a column of mercury, a pressure of a few centimetres sufficed to liquefy one of the portions completely. But this test is not so delicate as the one given above, viz. the entire increase of pressure from the beginning to the end of the liquefaction *.

20. The constancy of my results with the pure substances and the smallness of the admixture left, justify me in accepting an influence of the admixture upon the behaviour of the mixtures of a similar small amount.

Results obtained with the Mixtures.

21. The number of mixtures investigated was five. The composition (x parts of ethane in the volume in the gaseous state at one atmosphere) amounted to 0·18, 0·25, 0·43, 0·55, 0·76 respectively. The pressure and volume at the beginning and at the end of the condensation as observed at different temperatures are given in Tables I.–VII. The values of the volumes are only approximate. They are expressed in parts of the volume at 1 atm. and 0° C. For N_2O and C_2H_6 only one value for the pressures has been given. Tables VIII.–X. give the volumes for the temperatures 20°, 25°, and 26° C., as determined by graphical interpolation from the values observed.

* In filling a tube with a gas, which is compressed to a liquid afterwards, one works under unfavourable conditions for obtaining a pure substance compared to what can be obtained with liquids. The isopentane prepared by Prof. Young (Phil. Mag. [5] xxxviii. 1894, pp. 569–572) is remarkable in respect to purity. Here the increase of pressure appears to have disappeared entirely. Experiments by Battelli and others prove that even a pure liquid is not easily obtained.

Tables I.–VII.

I.—N_2O.

t.	p.	v_v.	v_l.
4·8	35·2	0·0206	0·0022
13·3	43·4	0·0161	
19·9	50·8	0·0125	
25·4	57·4[5]	0·0103	0·0027
31·5	65·4	0·0076	0·0031
36·0	71·9	0·0047	

II.—C_2H_6.

5·85	27·4	0·0248	0·0033
10·65	30·4[5]	0·0215	0·0034
15·4	33·8	0·0184	0·0036
22·4	39·7	0·0140	0·0038
29·35	45·9	0·0103	0·0046
31·0	47·6	0·0089	0·0049[5]
32·0	48·8	0·0064	

III.—Mixture 0·18 C_2H_6.

t.	p_1.	p_2.	vv.	v_l.
2·85	35·34	35·55	0 0205	0·0026[5]
11·8	43·57	43·91	0·0143	0·0029
19·05	51·48	51·81		
23·2	56·40	56·57	0·0094	0·0031
29·8	65·32		0·0052 (?)	

IV.—Mixture 0·25 (?) C_2H_6.

5·4	37·48	38·07	0·0177	0 0027
13·2	45·08	45·59	0·0131	0·0029
18·3	50·53	51·22	0·0111	0·0031
22·2	55·12	55·63	0·0094	0·0032
26·9	61·38	61·35	0·0066	0·0038
27·6	62·87	62·93	0·0065 (?)	0·0043
28·15	63·36		0·0046	

V.—Mixture 0·43 C_2H_6.

9·8	40·59	.....	0·0150	0·0030
14·3	44·96	45·57	0·0130	
18·6	.....	.....	.....	0·0034
20·5	51·75	52·29	0·0096	0·0035
24·6	56·67	57·01	0·0073	0·0041
26·05	58·42		0·0055 (?)	

Tables (*continued*).

VI.—Mixture 0·55 C_2H_6.

t.	p_1.	p_2.	v_v.	v_l.
6·4	35·59	36·86	0·0195	0·0036
11·35	40·02	41·05	0·0164	0·0038
18·4	47·02	48·06	0·0126	0·0043
25·4	54·87	55·46	0·0084	0·0050
26·05	56·12		0·0069	

VII.—Mixture 0·76 C_2H_6.

5·25	31·31	32·86	0·0217	$0·0035^5$
12·4	36·99	38·54	0·0173	$0·0037^5$
18·4	42·22	44·05	0·0140	$0·0040^5$
21·95	45·81	47·05	0·0118	$0·0042^5$
26·0	50·25	51·11	0·0092	0·0048
27·15	51·55	52·16	0·0083	0·0053
27·85	52·55		0·0066	

Tables VIII.–X.

VIII.—Volumes at 20° (fig. 3).

$x=0·0$.	0·18.	0·25.	0·43.	0·55.	0·76.	1·0.
0·0125	106	102	98^5	113	130	155
$0·0025^5$	30	32	35	42^5	41^5	37^5

IX.—Volumes at 25° (fig. 4).

$0·0104^5$	87	78	70^5	84^5	98^5	126
$0·0026^5$	33	35^5	42	48	45	40

X.—Volumes at 26° (fig. 5).

0·0101	85^5	73	58^5	69	92	99
$0·0027^5$	34	37	51	58	48	47

The results are laid down in fig. 2, and figs. 3, 4, and 5.

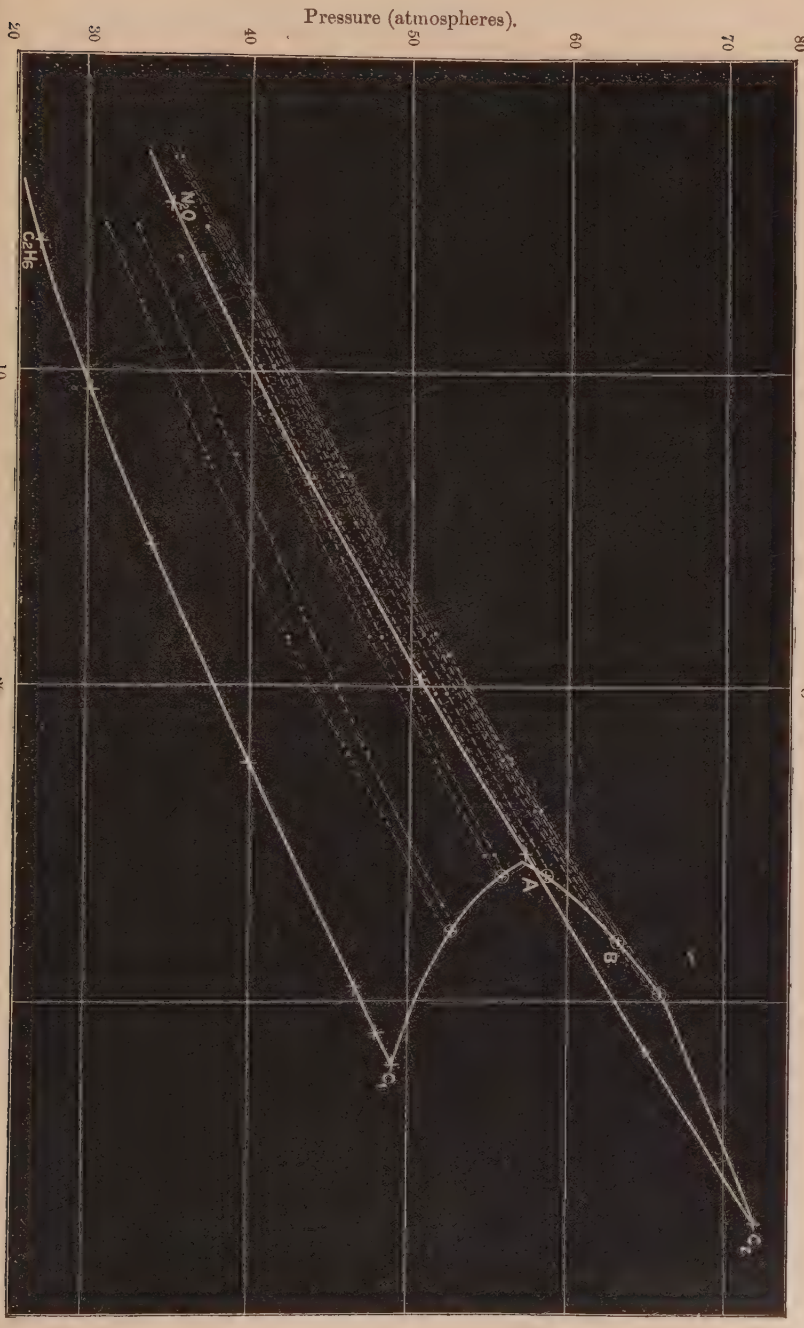
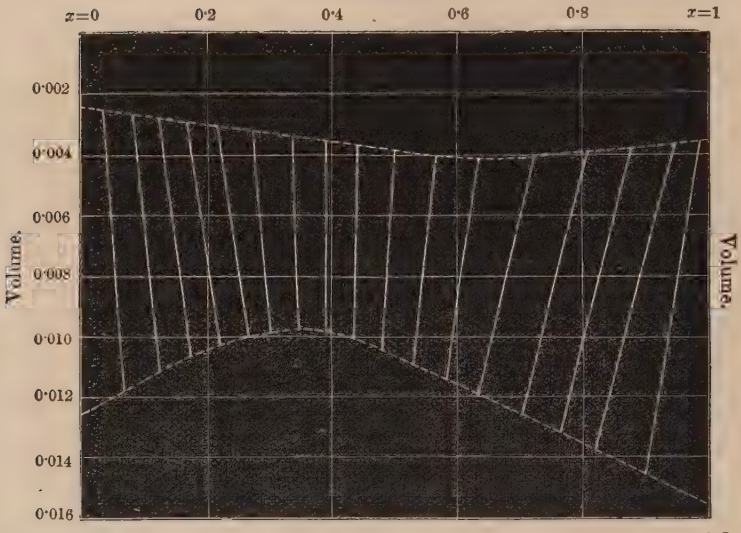

Pressure (atmospheres).
20
30
40
50
60
70
80
10
20
30
40
N_2O
C_2H_6
A
B
C
C_1
C_2

Fig. 2.

Fig. 3*. $t=20°$ C.



* There is a mistake in fig. 3 in so far as the straight lines near about $x=0{\cdot}2$ should be parallel to the γ axis, as in figs. 4 and 5.

Fig. 4. $t=25°$ C.

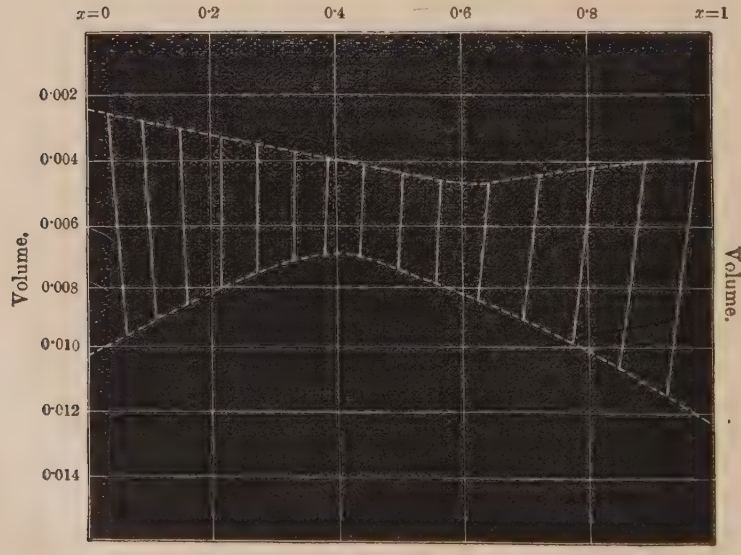
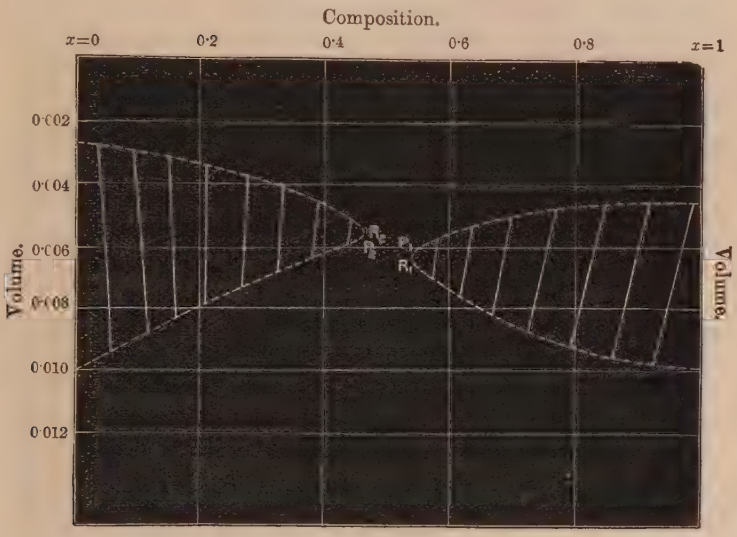


Fig. 5. $t=26°$ C.



22. The axes of coordination in fig. 2 are p and t. This figure may be compared with fig. 1, which represented the curves as they would have been if the phenomena had been as little complicated as possible.

The curve $C_2H_6-C_1$ is the vapour-pressure curve for ethane, N_2O-C_2 the same for nitrous oxide. C_1 and C_2 are the critical points. C_1ABC_2 is the plaitpoint-curve. The curves of the shape of loops are border-curves for the mixtures.

23. There are two striking differences between fig. 1 and fig. 2.

(1) The critical temperatures for a part of the mixtures lie below those for the components. By adding C_2H_6 (32°) to N_2O (36°), the critical temperature is lowered to a disproportionate extent. For a mixture containing $\pm 0{\cdot}1$ of C_2H_6 the critical temperature has gone down as far as to 32°, the c. t. for pure ethane. All mixtures containing more ethane than 0·1 have critical temperatures below 32°. Addition of N_2O to C_2H_6 therefore makes the critical temperature decrease instead of increase. The lowest critical temperature ($\pm 25{\cdot}8$) belongs to a mixture containing $\pm 0{\cdot}5$ of ethane.

A case like this has never been observed till now; van der

Waals's theory shows the possibility of the critical temperature lying outside those for the components*.

24. (2.) There is another difference between fig. 1 and fig. 2. The border-curves of the mixtures do not all of them lie between the vapour-pressure curves of C_2H_6 and N_2O. Some of them lie above the N_2O curve. It follows that at every temperature there is a maximum of pressure for one of the mixtures. From the figure it appears that this maximum lies somewhere between the mixtures the composition of which is 0·18 and 0·25, say $\pm 0{\cdot}2$. The border-curves of the mixtures 0·18 and 0·25 differ only very slightly and in the figure almost coincide. The meaning of this is that the maximum belongs to almost the same mixture at all temperatures represented in the figure. If the mixture for which the pressure is a maximum varied quickly with change of temperature, the border-curves of the mixtures in that neighbourhood would intersect at perceptible angles. If we tried to draw the curve giving the maximum pressure at any temperature, it would lie a very little above the border-curves for $x=0{\cdot}18$ and $x=0{\cdot}25$, and be about parallel to those. This curve we shall call the *maximum-curve*.

25. There is another remarkable quality of the border-curves in this region near the maximum, viz. the narrowness of the border-curves, *i. e.* the very small increase of pressure during the condensation. The value of this increase amounts to 0·2–0·3 atm. for the first mixture, which is only a very little more than what still remained in the pure nitrous oxide itself†.

* There is one instance of a mixture, the critical temperature of which lies *above* those for the components, observed by Dewar, namely, of CO_2 and C_2H_2 (Proc. Roy. Soc. of Lond. xxx. p. 543).

† The increases for the second mixture (0·25) are somewhat higher, viz. $\pm 0{\cdot}6$ atm., which must be due to a somewhat larger impurity of that mixture. Probably the pressures of this mixture are therefore a little too high at the same time. The maximum will therefore be nearer to the first mixture (0·18). That is why I have put it equal to $\pm 0{\cdot}20$. On the whole the values for the increase of pressure are a little irregular, which is quite natural considering the difficulty of these observations with mixtures. From the observations one might, perhaps, conclude that the maximum with rise of temperature shifts a little towards the N_2O; but as this seems rather uncertain, I prefer taking it constantly equal to 0·20.

We may therefore almost take it equal to zero. This agrees with what follows from the theory of mixtures. In a maximum-point (and also in a minimum-point) the two coexisting phases have the same composition (x) though different volumes (v), and there is no increase of pressure during the condensation. In order to determine the exact value of the maximum, a large number of mixtures lying about $x=0{\cdot}2$ should be investigated: only the small admixture in the components themselves would of course impede the fixing of the maximum-curve.

26. In itself the existence of a maximum (or minimum) pressure is not a new phenomenon. Guthrie*, Konowalow†, and others have found the same with different mixtures. Only, so far as I know, a maximum (or minimum) has never been traced up to the critical temperature. In Konowalow's mixtures the maximum appears sometimes to shift with change of temperature, and accordingly probably to disappear below the critical temperature. The above results prove that this need not be the case at all. This fact may be expressed in this manner: the maximum-curve need not reach the vapour-pressure curve of one of the substances. In my experiments it reaches the plaitpoint-curve, near B.

27. These results will be much better understood by inspecting figs. 3, 4, 5. The curves in these figures give the relation between the composition of the mixtures and the volumes at which the condensation begins and at which it ends (*vid.* § 1 *sqq.*), and may at the same time be considered as the projection of the connodal curves of the plait in van der Waals's surface upon the v–x plane. The figures belong to the temperatures 20°, 25°, and 26° C. respectively.

28. If the phenomena were such as would correspond to fig. 1, the plait with rise of temperature would get narrower near the C_2H_6 plane ($x=1$). At 32° C. the curve would loose itself from the v-axis for $x=1$, whilst forming a plait-point there; above 32° C. it would withdraw towards the N_2O axis ($x=0$), where it would disappear at 36° C. (critical temperature of N_2O).

29. However, this is not what really happens. With rise

* Phil. Mag. [5] xviii. p. 510 *et sqq.* † Wied. *Ann.* xiv. p. 34.

of temperature the plait becomes narrower somewhere near the middle. Consequently, at a temperature far below 32° C., near 25°·8 C., the plait divides into two parts. At that moment two plaitpoints appear (P_1 and P_2)*. The two parts into which the plait is divided henceforth withdraw towards $x=0$ and $x=1$ separately. At 32° C. the right-hand plait disappears at $x=1$. At 36° C. the left-hand plait disappears in $x=0$. Above 36° C. there is no plait left: the surface is convexo-convex henceforth, and all its points represent stable phases.

30. A maximum pressure (or minimum) manifests itself in the v-x figure in the position of one of the lines connecting the pairs of coexisting phases being parallel to the v-axis. The lines on both sides of the maximum line will be turned in opposite directions (with a minimum the direction in which the lines turn is the opposite of what it is here). But the angles of the lines are very small in the case of C_2H_6 and N_2O. On the right-hand plait the lines differ more: the increase of pressure is accordingly larger on that side of the surface. In the figure the turning of the lines had to be exaggerated in order to show their direction.

31. The critical phenomena of the mixtures were much simpler than I expected to find them. All the mixtures showed normal condensation up to the critical point, and a difference between plaitpoint temperature and critical temperature could not be determined with any certainty. The probable cause of this disagreement I shall refer to after having deduced more completely the theoretical consequences of the experimental results laid down in fig. 2, and figs. 3, 4, 5 (*vid.* §§ 43–46).

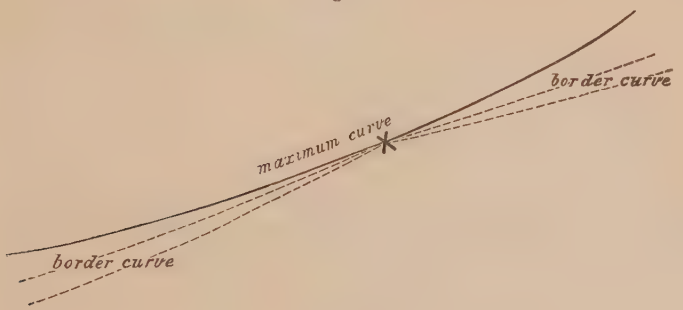
Theoretical Conclusions to be drawn from the Experimental Curves.

32. A. *Maximum-Curve.*—It may be proved that the border-curve of a mixture for which the pressure becomes a maximum

* In two interesting papers (Wien. *Ber.* xcviii. pp. 1154–91; *Archives Néerl.* xxiv. pp. 57–98, 295–368) Prof. Korteweg has derived the geometrical properties of the plaits and plaitpoints. The case occurring here, viz. the formation of two plaitpoints of the same kind at the same time, is discussed on pp. 303–305.

touches the maximum-curve with both its branches. This is represented in fig. 6. In every point of the maximum-curve a similar meeting of three curves takes place. If the maximum-mixture does not change much with the temperature

Fig. 6.



(as we found was the case with C_2H_6 and N_2O), the border-curve of the maximum mixture must have nearly shrunk to *one* curve coinciding with the maximum-curve.

33. Apparently the p–t figure is not at all convenient for showing the situation of the border-curves near the maximum-curve. The border-curves for the mixtures situated on both sides near the maximum-mixture cover each other in the figure. In a case like this it is much better to add as a third axis of coordination the x-axis, and to draw the p–t-curves for the mixtures each in its own plane. The curves together in this manner form the p-t-x-surface. Sections of the p-t-x-surface perpendicular to the t-axis again give curves having the shape of loops (p–x-curves), which may be considered as an extension of Konowalow's curves*: he only gives the upper branches of the p–x-curves. A complete p–x-curve is given by Prof. van der Waals in his treatise †.

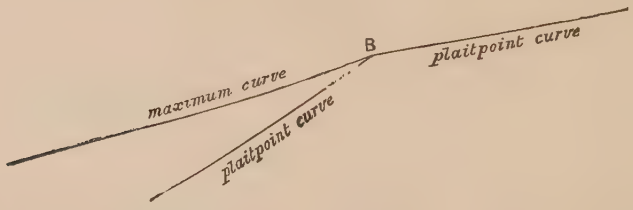
34. The maximum-curve meets the plaitpoint-curve in B. Fig. 7 shows the manner in which the three curves (the maximum-curve and the two branches of the plaitpoint-curve) meet in B. It will have to be decided theoretically whether, perhaps, the plaitpoint curve has no singular point in B, in which case the maximum-curve would touch it in B.

* Wied. *Ann.* xiv. p. 34.

† *Arch. Néerl.* xxiv. p. 21.

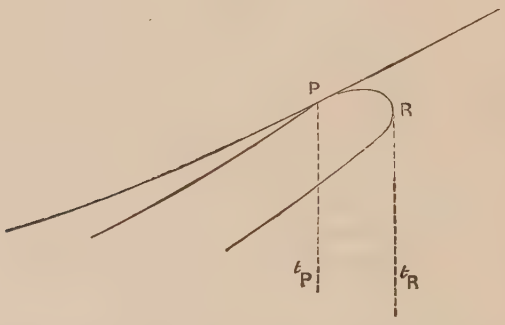
35. B. *Critical Phenomena.*—The plaitpoint-curve (fig. 2) consists of three parts, being situated between both the critical points C and C_2, and separated by the two points A and B.

Fig. 7.



A is the meeting-point of two branches of the plaitpoint-curve, where the critical temperature is lowest*. In B the maximum-curve meets the plaitpoint-curve.

Fig. 8.



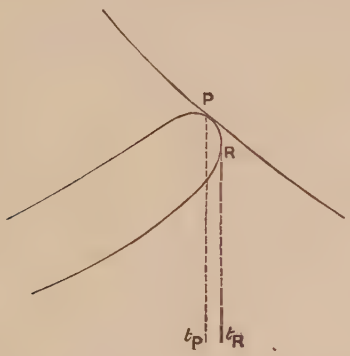
36. In the part C_2B the relative position of plaitpoint-curve and border-curves is like fig. 8. P lies in the direction we called beyond R, and the border-curves touch the plaitpoint-curve on its right side. The mixtures having their plaitpoint between C_2 and B, *i. e.* containing less than 0·2 C_2H_6,

* The existence of a singular point in A was suggested to me by the experimental curves (fig. 2, *vid.* § 42). Professor van der Waals, to whom I showed my experimental results, told me that he has theoretical reasons for believing that the plaitpoint-curve is continuous during its whole course, so that neither A nor B would be singular points. The conclusions drawn in §§ 40–42 and figures 11 and 12 entirely depend upon the existence of a singular point in A. There is, however, no connexion between those and the rest of this paper. Professor van der Waals will publish his results ere long.

therefore must have retrograde condensation of the first kind (r.c. I.) between the temperatures t_P and t_R.

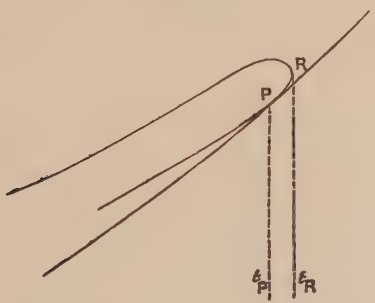
37. In the part C_1A the curves are situated as in fig. 9. The border-curves lie on the left-hand side, but the plait-

Fig. 9.



point-curve falls. P lies beyond R. The mixtures having their plaitpoint here, *i.e.* containing more than 0·5 C_2H_6, must also have r.c. I. between t_P and t_R.

Fig. 10.



38. The part BA, however, fulfils the condition for the existence of r.c. II., as is shown in fig. 10 (*vid.* § 6). The plait-point-curve rises, and the border-curves lie on its left side. R lies beyond P. In this region lie the mixtures the composition of which is between 0·2 and 0·5 C_2H_6.

In consequence of the complexity of the curves as compared to fig. 1, the region of r.c. II. is a great deal smaller than it would have been according to fig. 1 (BA instead

of C_1C_2). It is easy to see that this was the only thing which could happen: r.c. II. could not disappear entirely.

39. These rather strange conclusions are entirely made clear by figs. 3, 4, 5. These represent exactly the same phenomena, only in a different manner. If P lies above R we have r.c. I.; if it lies below R, we have r.c. II. At first, after the dividing of the plait, the plaitpoints P_1 and P_2 lie on opposite sides of R_1 and R_2 in the two plaits. This corresponds to the existence of r.c. I. below A, and r.c. II. above A in fig. 2. While with rise of temperature the plait P_2R_2 shrinks together, R_2 approaches the maximum-line. P_2 approaches R_2 at the same time, and at the moment that the maximum reaches the end of the plait, P_2 and R_2 coincide. At that moment there is no retrograde condensation. The mixture $x=0{\cdot}2$ behaves at its critical point like a pure substance. P_2, however, now continues to move upwards, and henceforth lies a little above R_2. That explains the existence of r.c. I. between B and C_2. If there had not been a maximum, r.c. II. would have existed all the way from A to C_2.

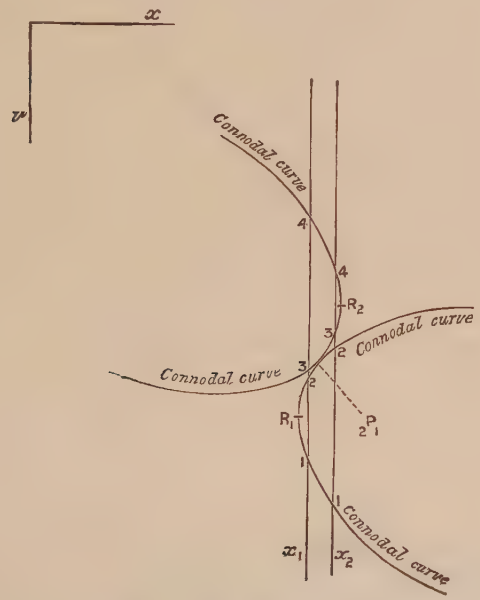
40. The critical phenomena near the point where the plait divides into its two branches ($t=25{\cdot}8$, $p=57{\cdot}7$ atm.) are of a rather complex nature. This will be understood by the contemplation of fig. 11, where the two branches of the connodal curve at the moment of parting have been drawn on a much larger scale.

Let us consider the condensation of the mixtures x_1 and x_2 separately. It will be seen (*vid.* § 1) that the mixture x_1 in 1 begins to show a liquid phase which increases, decreases, and disappears in 2 (r.c. I.). Then, in 3, the liquid appears again, and in 4 the whole mixture will be liquid (normal condensation). Mixture x_2 liquefies in 1: the liquefaction is at an end in 2 (normal condensation): in 3 a vapour phase appears which disappears in 4 (r.c. II.).

41. Quite close to this temperature (below and above it) similar complicated phenomena will exist. A little above $25{\cdot}8$ there are even some mixtures which show first r.c. I. and then r.c. II. successively with compression. But as soon as the plaits have moved so far that there is no x-line cutting both plaits, the critical phenomena become the ordinary phenomena for a mixture (r.c. I. or II.).

42. The p–t-curves in the neighbourhood of A have a more complicated character, corresponding to the behaviour of the plait (fig. 12). The two branches of the experimental plaitpoint-curve meet in a singular point. The border-curves show a doubling, which disappears at a small distance from A. A fuller explanation of the figure seems hardly necessary. For clearness' sake only two border-curves have been drawn in the figure on an exaggerated scale.

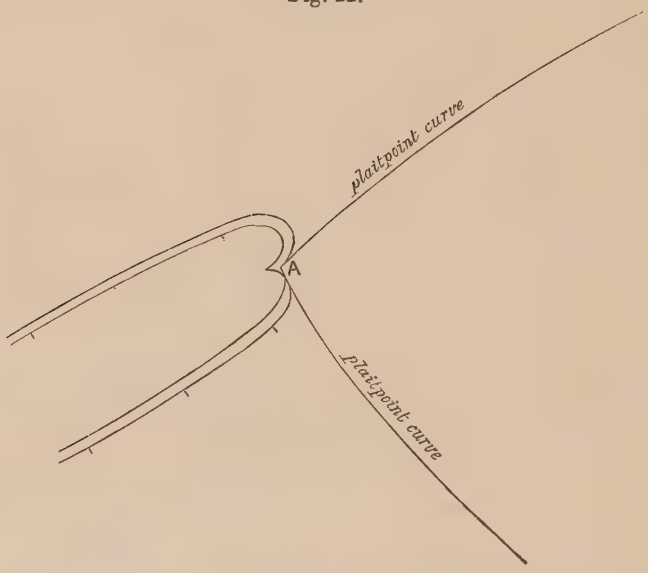
Fig. 11.



43. How is it that in my experiments the mixtures did not show any of those critical phenomena partly of a so complicated nature, and almost behaved like pure substances near their critical points? (§ 31). The reason lies at hand : I have pointed out the smallness of the increase of pressure, *i. e.* the approximate parallelism of the straight lines in fig. 3 (§ 30), and the exceeding narrowness of the loops (border-curves) in fig. 2 (§ 25). Accordingly, as will be noticed in both figs. 2 and 5, the two critical points P and R lie close together, and the distance between the temperatures of the plaitpoint and the critical point of contact (t_P and t_R), for the same mixture,

can be very small only. An estimation from the original figure 2 gives $\pm 0°{\cdot}1$ C. at the utmost for the distance between t_P and t_R, and in some parts of the plaitpoint-curve—for instance near B—much less still. Now in order to fix so small a difference the temperature ought to be perfectly constant for a long while, which was not the case in my water-vessel.

Fig. 12.



There were slow changes, which of course did not prevent the determination of the critical point taken as a whole. I think this circumstance may be taken as a sufficient explanation of the disagreement between theory and experiments.

44. However, there is another cause which must have co-operated in confusing the pure phenomena, viz. the influence of gravitation. It was Gouy* who, in the case of pure substances, first pointed out the importance of this factor near the critical point, where the substances become so highly compressible. In the case of mixtures the influence of gravitation is not of a quite simple nature. The result is this :

* *Compt. Rend.* cxv. p. 720, cxvi. p. 1289; *cf.* Kuenen, 'Communications, etc.' No. 8, p. 10.

near the plaitpoint there is a small region in which the complete process of the condensation is confused ; namely in this manner, that with compression at a certain moment the liquid surface between the phases disappears at some distance from the ends of the tube. In this manner the process of retrograde condensation is cut off halfway ; and if the distance between the two critical temperatures is very small, the phenomenon may perhaps disappear entirely *. This suggests the use of horizontal, or at least nearly horizontal, tubes for experiments on the critical phenomena.

45. Now in this region, where gravitation plays an important part, the stirring of the substance cannot be of any avail ; on the contrary, the equilibrium, which is very much influenced by gravitation, is spoilt rather by mixing together the different layers. So in this region the only thing we can do is, to wait a long time, and Gouy's experiments with an almost pure substance show that "long" means "days" here ; and of course that would be no use unless the temperature and the volume could be kept absolutely constant, which is practically impossible.

46. Though the special critical phenomena predicted by means of van der Waals's theory have escaped observation so far, there is no reason to doubt their reality or to see any contradiction between them and my experimental results, I believe.

47. Some of the results arrived at in this investigation may be enumerated here once more :—

1. The mixtures of C_2H_6 and N_2O containing more than 0·1 of C_2H_6 have critical temperatures lying beneath those of the substances (§ 23).

2. The pressures of the mixtures lie partly above those of N_2O, and accordingly show a maximum situated near 0·2 C_2H_6 (§ 24).

3. The maximum does not disappear with increase of temperature, but remains up to the critical region : the maximum-curve reaches the plaitpoint-curve (§ 26).

4. The mixtures ranging between 0·2 and 0·5 C_2H_6 have r.c. II., the rest r.c. I.

* Kuenen, *Verslagen kon. Akad. Amsterdam*, 25 Mei, 1895.

I intend now to investigate mixtures of acetylene and carbonic acid, a group of which according to Dewar* has critical temperatures lying above those of the components. If I should be able to confirm this result, I shall treat that combination in the same manner experimentally and theoretically as I have done the combination of C_2H_6 and HN_2O in this paper.

The experiments described in this paper have been carried out in the Physical Laboratory at Leiden, to the Director of which, Professor Kamerlingh Onnes, I am indebted for continuous and invaluable advice and help.

Discussion.

Prof. Carey Foster and Prof. Ramsay complimented the author on the very lucid way he had expounded a by no means easy subject.

Dr. Sidney Young congratulated the author on the able use he had made of his lucky discovery of two bodies such that their mixture should have a lower critical temperature than that of either of the pure substances. Prof. Ramsay and he (Dr. Young) had made experiments on the vapour-pressure of mixtures of alcohol and ether, and had found great difficulty in preventing the separation of the components when the volume was altered, and he could therefore thoroughly appreciate the utility of the author's device for overcoming this difficulty. They had also experienced considerable difficulty in filling the tube with a mixture of known composition and free from air, and he considered that when dealing with mixtures it was better to employ gases, although they could not be obtained in so perfect a state of purity as liquids, on account of the greater ease with which a mixture of known composition can be obtained. The plan of making separate observations on the pure substances was a good one, and, considering that the author measures the increase of pressure during the process of condensation, so that any air which happens to be present produces the maximum effect, the small rise in pressure obtained indicated a high degree of purity in the gases employed. He would

* Proc. Roy. Soc. of Lond. xxx. p. 543.

like to ask the author if, in the case of mixtures, he found it possible to determine accurately the point where condensation commenced and ended, for with the alcohol and ether mixtures they found it very difficult to determine these points. He also hoped the author would continue his observations in the direction indicated in the paper.

Mr. Inwards suggested that, in the case of liquids which act on iron, the iron stirrer could be enclosed in glass or india-rubber. It might also be possible to obtain more efficient stirring by means of a small fan or propeller worked by an electro-magnet rotating outside the tube.

Dr. Kuenen, in his reply, said that, when the mixtures were well stirred, the pressures at which condensation commenced and ended were well marked.

XLVII. *An Electromagnetic Effect.* *By* F. W. Bowden*.

Some time ago, under the direction of Prof. Perry, I was making some experiments suggested by Dr. Larmor. The following curious observations were made, and as Dr. Larmor thinks them distinct from his own object, I beg leave to bring them before the notice of the Physical Society. In fig. 1, N and S are nearly cubical blocks of iron whose edges are about 6 centim. long, forming the poles of an electromagnet. The field between N and S near the middle was about 1100 C.G.S. A is the end view of a glass tube, 4 millim. internal diameter and about 30 centim. long, containing mercury and connecting two large mercury troughs, and a current of about 40 amperes was sent through it. A stand-pipe, B, 2 millim. diameter, indicated the pressure of the mercury. When the current passes in one direction (out from the paper) the mercury rises 15 millim. in B. When the current is reversed, the mercury falls 15 millim. Reversing the magnetic field produces the same effect as reversing the current.

With the tube in the position shown in fig. 2, the effects

* Read June 28, 1895.

were of the same kind but not so marked, the rise and depression being about 10 millim. As the tube was lifted more and more out of the field, the effects became less and less.

The field being vertical as in fig. 3, the mercury *rose* in the stand-pipe when the current passed, and in whatever direction the current passed; reversing the current did not

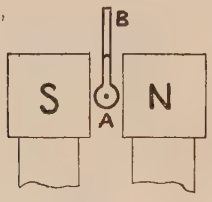


Fig. 1.

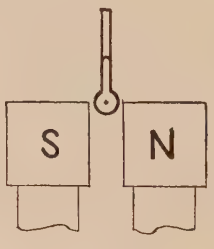


Fig. 2.

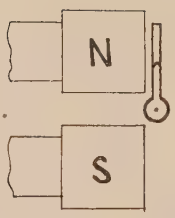


Fig. 3.

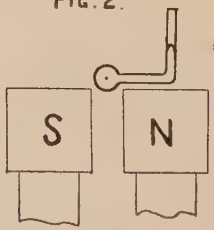


Fig 4

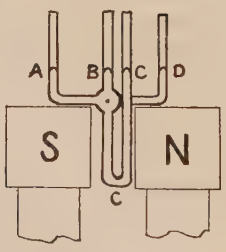


Fig 5.

reverse the pressure-effect produced. Also reversing the field did not reverse the pressure-effect produced.

I again used a horizontal field as in fig. 4, the stand-pipe showing now the side-pressure in the tube parallel to the field. It was my intention to let fig. 4 really represent fig. 3 turned through a right angle, and again the mercury always rose in the stand-pipe, whatever the direction of the current or field.

Lastly, I let four stand-pipes communicate with the middle of the tube. The current passing in one direction, the mercury in B rose, in C fell, and in A and D rose only momentarily during the starting of the current. When the current was reversed, the mercury in B fell and in C rose, and rose momentarily in A and D.

The non-reversible effects of figs. 3, 4, and in the tubes A and D of fig. 5 are probably due to curious motions of the mercury, but it seems difficult to understand how. They do not occur when the tube is far away from the magnetic field.

Discussion.

Prof. S. P. Thompson said that there appeared to be three unexplained effects—one proportional to the current and the field, and reversible; another, independent of the direction of the current or of the field; and a third, which only occurred while the current was changing in strength. In addition there may be a fourth effect, which up to now has not been noticed. The motion of the mercury column in fig. 1 was in the opposite direction to that of the drag on a conductor carrying the current. An apparent rise in pressure might be due to a decrease in the density of the mercury due to the heat developed by the current.

Mr. Blakesley asked if the author had noticed any changes in level in the mercury reservoirs at the ends of the tube.

The Author, in his reply, said the reservoirs at the ends were so large that no changes of level were appreciable.

XLVIII. *The Electrical Properties of Selenium.* *By* Shelford Bidwell, *M.A.*, *F.R.S.**

§ 1. *Preliminary*†.

Selenium, which is supposed to be an elementary substance, is capable of existing in several distinct modifications. The amorphous variety consists either of a finely divided red powder, or of a vitreous mass which resembles black glass in appearance and does not conduct electricity. Amorphous selenium melts at about 100° C., but at temperatures between 100° and 217° the black semi-liquid mass gradually hardens into a grey metallic-looking solid. This consists of Se in the crystalline form : it melts at 217°, and is a moderate conductor of electricity, its conductivity being temporarily increased by the action of light. This peculiar influence of light upon Se has attracted much attention, and below is given a list of published papers relating to the subject‡.

§ 2. *Selenium Cells.*

Any device consisting essentially of a mass of crystalline selenium in combination with two metallic electrodes, and so arranged as to expose a relatively large surface for light to act upon is commonly, but not very appropriately, termed a "Selenium Cell." So many inquiries have reached me as to the construction of the sensitive cells which I have at different

* Read June 28, 1895.

† A summary of the principal results will be found at the end of the paper.

‡ Willoughby Smith, Journ. Soc. Tel. Eng. ii. p. 31 ; Earl of Rosse, Phil. Mag. March 1874, p. 161 ; Sale, Proc. Roy. Soc. 1873, p. 283 ; Phil. Mag. March 1874 ; Werner Siemens, Phil. Mag. November 1875, p. 416 ; Draper and Moss, 'Chemical News,' xxxiii. p. 1 ; Moss, Proc. Roy. Soc. May 11, 1876 ; Adams and Day, Proc. Roy. Soc. 1876, p. 113 ; Phil. Trans. 1877, p. 313 ; C. W. Siemens, Proc. Roy. Inst. 1876, p. 68 ; Sabine, Phil. Mag. June 1878, p. 401 ; Graham Bell, 'Nature,' xxii. p. 500 ; Proc. Nat. Acad. Sci. April 1881 ; Shelford Bidwell, Phil. Mag. April 1881, January 1883, August 1885, March 1891 ; Fritts, 'Electrical Review,' March 7, 1885, p. 208 ; Minchin, Phil. Mag. March 1891, p. 207.

times exhibited before this Society and elsewhere, that I venture to think a short account of the process may be usefully given here.

A slip of mica about 55 millim. long, 17 millim. wide, and 0·4 millim. thick, is sandwiched between two semi-cylinders of boxwood about 18 millim. in diameter and of somewhat greater length than the mica, the ends being held together by screws. The whole is smoothed down in a lathe until the edges of the mica are flush with the surface of the wood. A screw of 16 threads to the centim. (40 to the inch) is cut upon the middle portion of the cylinder for a length of 45 centim. The mica is then removed from the wood, and two small holes are drilled near each of its ends. An annealed copper wire 0·19 millim. in diameter (No. 36 s.w.g.) is tightly wound around the notched portion of the mica, the turns being made to occupy alternate notches, and its ends are secured by passing them through two of the drilled holes. A second wire is then wound into the other notches, its turns alternating with those of the first. These wires constitute the electrodes, and great care is taken that they do not touch each other at any point.

The next step is to apply the selenium. A brass plate 2 millim. thick is supported upon an iron tripod and covered with a sheet of thin mica; upon this is laid the prepared mica slip, small weights being placed upon its ends to steady it. The surface of the wired portion of the slip is evenly covered with 1 gramme (or a little less) of powdered vitreous selenium, and a small Bunsen burner is lighted beneath the brass plate. In a few minutes the greater part of the Se will melt: some of it, however, will probably crystallize, forming hard grey lumps, and when this occurs the heat must be continued, and if necessary increased, until all the grey lumps have disappeared. Then the Se is worked smoothly and uniformly over the slip with a steel spatula, particular care being taken that the surface is covered quite up to the edges. This operation is often found a troublesome one, but if the temperature be properly regulated, there is little difficulty about it. When the temperature is too low, hard crystalline lumps are formed; when it is too high, surface-tension causes the selenium to gather up into drops, and it becomes as impossible to spread as if it were mercury. The Bunsen

flame should be adjusted so that the temperature is only just above the melting-point, 217°; the selenium then assumes a plastic semi-fluid condition and can be easily manipulated.

When a satisfactory surface has been secured, the cell is immediately removed by means of forceps and placed upon a thick copper plate to cool quickly. The Se surface should at this stage be black and lustrous, and the resistance between the electrodes sensibly infinite.

The Bunsen flame having been turned down sufficiently to lower the temperature to about 120°, the cell is replaced upon the hot plate. In a few minutes parts of its bright surface become dimmed, and shortly afterwards the whole turns a dull grey colour. The temperature is then cautiously raised until signs of melting just begin to appear, generally near one of the edges. When this occurs the burner is instantly withdrawn and the flame slightly lowered. The darkened spot recrystallizes in the course of a few seconds, and the burner is then replaced and left for four or five hours, during which time the temperature of the Se should be only a few degrees below the melting-point. Another hour is occupied in slowly cooling the cell, the flame being gradually lowered and finally extinguished. This process of long heating and slow cooling is generally spoken of as "annealing."

The resistance of such a cell as that described is generally from 50,000 to 100,000 ohms in the dark, and 50 or 60 per cent. less in diffused daylight. If alternately screened and exposed, it will with an electromotive force of 50 volts or upwards easily actuate an ordinary telegraph relay.

§ 3. *Hypothesis as to the Action of Light upon Selenium.*

Selenium as supplied commercially is never free from impurities, and indeed I have lately been informed by a distinguished chemist, who has given some attention to the subject, that perfectly pure selenium has not yet been obtained. Graham Bell states that the samples collected by him in different parts of the world were found to contain, among other things, the metals lead, iron, and arsenic.

Ten years ago I suggested * that metallic selenides, whether

* Proc. Phys. Soc. vol. vii. p. 129; Phil. Mag. August 1885, p. 178.

originally existing as impurities in the Se or formed at the expense of the electrodes during the process of "annealing," might play a very important part, not only in relation to the conductivity of crystalline Se, but also in bringing about the apparent change of its resistance under the influence of light. According to my hypothesis, the conductivity of Se depended mainly upon the selenides which it contained. I supposed the conduction to be of a truly electrolytic character, the current decomposing the selenides, and depositing upon the anode amorphous Se and upon the kathode the various metals. Amorphous Se is a non-conductor: unless, therefore, the deposited Se combined more or less freely with the metal of the anode, forming upon it a layer of conducting selenide, the resistance of a Se cell would, under the influence of a current, soon rise to infinity. It has been shown that Se does slowly unite with at all events some metals when merely brought into contact with them, and I ventured to suggest that light played its part in reducing the resistance by facilitating this union. The action would occur not only at the anode, but throughout the body of the Se, the recombination of the separated molecules of Se and the metal (forming the "Grotthuss chain") being similarly assisted.

This hypothesis would, as I showed, explain many observed facts which could not otherwise be readily accounted for, and I adduced in support of it several arguments which need not here be repeated. But the hypothesis postulated two important assumptions which I was not able at the time (nor when I returned to the subject five years later) to justify by experimental evidence. It assumed that solid metallic selenides conduct electrolytically, and that the combination of selenium with a metal is accelerated by the action of light.

My recent experiments, some of which are discussed in the present paper, were undertaken primarily with the object of testing these two assumptions. In the course of the investigation, however, many other interesting points presented themselves for consideration, and some of the results arrived at are also here recorded. The experiments are described in the order which appeared to be most convenient; it is of course not that in which they were actually performed.

§ 4. *The Effect of Annealing upon the Specific Resistance of Crystalline Selenium.*

The resistance of Se which has been crystallized and annealed out of contact with any metal appears to be always much greater than when metallic electrodes have been fused into it in the usual fashion. It also depends to a large extent, and in a manner which is not yet fully explained, upon the treatment which the Se has received.

Exp. 1.—A number of disks were prepared by casting Se in a mould formed by placing a glass ring, such as is used for microscope slides, upon a glass plate. The thickness of a disk was made approximately uniform, and its surfaces polished by rubbing upon fine glass-paper laid upon a sheet of plate glass. The disk to be tested was inserted between pads of vulcanized rubber covered with tinfoil, which constituted the electrodes, and the whole was placed between hinged boards and loaded with a weight of 28 lbs. (12·7 kilos). It is unnecessary to describe the tests in detail, inasmuch as the only result arrived at was the negative one that crystalline Se has no definite specific resistance. In different tests of disks prepared from the same sample and as far as possible in the same manner, it varied from 33 megohms to 1630.

The specific resistance is certainly not always diminished, as is generally believed, by prolonged heating at a high temperature ; *i. e.* between 200° and 217°. It is indeed often increased after such an operation, as in the following extreme instance.

Exp. 2.—A disk of Se was crystallized and heated for an unrecorded number of hours in a copper air-bath at about 200°. Its specific resistance was afterwards found to be 38·5 megohms. It was again heated at the same temperature for three hours. When cold its specific resistance was 660 megohms. In both cases it was cooled slowly.

§ 5. *Action of Selenides.*

On the other hand, prolonged heating always diminishes the resistance of a Se "cell" having electrodes fused into it. This I have attributed to the action of the conducting metallic

PHYSICAL SOCIETY OF LONDON.

ABSTRACTS OF PHYSICAL PAPERS

FROM FOREIGN SOURCES.

SEPTEMBER 1895.

GENERAL PHYSICS.

604. *Physical Properties of Solid Carbonic Acid.* **P. Villard.** (Bull. Soc. Franc. Phys. 66. 1895.)—Carbonic acid crystallises at $-57°$ under a pressure of 5·1 atmos. The crystals have no action on polarised light. The liquefied gas boils at ordinary pressure in an open vessel at $-79°$, the former boiling-point of $-60°$ corresponding to a pressure of about 4 atmos. Ether does not lower the temperature of the snow, but methyl chloride when added to it yields a true freezing-mixture, the temperature falling from $-65°$ to $-85°$. Nitrous oxide does not dissolve carbonic-acid snow. In vacuo a temperature of $-125°$ can be obtained from carbonic acid alone, and the author thinks that it alone would be sufficient to liquefy oxygen with ordinary laboratory apparatus. S. R.

605. *Interpretation of Lunar Photographs.* **Lœwy** and **P. Puiseux.** (C. R. 121. pp. 79–85, 1895.)—In the second paper the authors discuss their own enlargements on glass of their photographs. The fairly uniform appearance of the moon is in accordance with the theory of Laplace. Besides the predominating rings there are systems of less strongly marked straight lines, which have no connexion with the relief of the area around them. These lines represent the refusion seams of already cooled masses, and are totally different from telluric valleys. They are almost rigorously rectilinear, without ramifications, and of equal width and depression below the level around throughout their length; there are no indications of erosion and sediments. Two or three systems of such groups of parallel lines can be distinguished, which

are frequently tangential to the rings. Thus Albategnius is inscribed on a parallelogram whose acute angles are again cut off by lines, so that a hexagon is produced. Such polygons are frequent, and the lines are often tangents to two rings. As long as there was no accord between the rotational and revolutional periods of the moon, these junction-lines could not remain fixed. Friction between masses of solidified scoria has destroyed projecting parts and produced long fissures, afterwards congealed, such as we see on ice-floats. That friction was tidal and, owing to the irregular shapes of the floating islets, gravitational, giving rise to secondary lines showing a less regular grouping. On the whole, however, the lines are equatorial near the equator and more meridional near the poles. Two circumstances support these views. If the lines represent ancient fissures in which the liquid mass was afterwards congealed, they would coincide with lines of least resistance, and we find indeed along them many small craters. Further, if, owing to continued contraction, an eruption, or tidal influences, the pressure should have been reduced at some spot under the crust, circular hollows might form and the lines would limit the affected area; hence the straight outlines of areas of depression. The authors are preparing a map on the scale 1 : 1,800,000. H. B.

---

606. *Solubility of Metals in Mercury.* **Gouy.** (J. Phys. 4. pp. 320–321, 1895.)—The author finds that the ratio of the mass of metal dissolved to the mass of solution is as follows:—

Iron	0
Copper	·00001
Silver	·0003
Gold	·0013
Tin	·006
Bismuth	·012
Lead	·013
Zinc	·018
Cadmium	·040
Darcet's Alloy	·38

These are at a temperature 15° to 18°. At higher temperatures the solubilities increase rapidly. J. W. C.

---

607. *Linkwork with Jointed Quadrilaterals.* **N. Delaunay.** (J. Phys. 4. pp. 315–320, 1895.)—The author describes first a "projector" in which a jointed quadrilateral is made to run with two of its points, equidistant from an angle D, confined to a straight slot; when the apex of the angle B, opposite to D, describes any curve, the apex of the angle D describes an orthogonal projection of that curve. For example, if B describe a circle, D describes an ellipse ("ellipsograph"), the excentricity of which varies with the

distance between the slot and the angle D. In a third piece of apparatus B and D are allowed to run freely in a straight slot; A and C are left free; but an additional pair of arms, say BC′ and DC′, shorter than BC and DC, is so arranged that the pin C′ may run back and fore in a slot in a bar pivoted on the midpoint of that bar which carries the slot in which B and D run. A and C then describe a hyperbola ("hyperbolograph"). M. Delaunay also describes a "duplicateur" in which, through the addition of other bars, he makes one rotation of a point O result in two rotations of the point B, without dead points; and he gives a development of Tchebishtcheff's apparatus for transforming rotation into alternative movement, the effect of the new contrivance being to transform a rotation into four motions (reciprocating and approximately rectilinear, and at right angles and parallel to one another) of the four outer points of the apparatus. A. D.

---

608. *Kinetic Theory of Heavy Fluids.* **L. Houllevigue.** (J. Phys. 4. pp. 301–305, 1895.)—For his starting-point the author refers to an article by Clausius in C. R. 1870, p. 1314; the abstractor refers the English reader for the same to pp. 61–63 of Watson's 'Kinetic Theory of Gases,' where can also be gathered the definitions of many of the symbols used below. In the case of a liquid in a condition of stationary motion,

$$W = -\tfrac{1}{2}\Sigma(Xx+Yy+Zz).$$

The author considers a mass of fluid, in equilibrium, enclosed in a cylinder, infinitely flat, of cross section S, whose generators of height dz are parallel to the vertical axis OZ, and lets z_0 represent the distance of the lower end from the plane xy, p the pressure on the upper end, and $p+dp$ the pressure on the lower end, forces which are normal in the case of stationary motion. He evaluates on this hypothesis the value of the *virial*; *i. e.*, of the expression

$$-\tfrac{1}{2}\Sigma(Xx+Yy+Zz).$$

He shows that the virial of the little cylinder equals

$$V_1+\tfrac{1}{2}\varpi\left(z_0+\frac{dz}{2}\right)+\tfrac{1}{2}p\mathrm{S}(z_0+dz) \\ -\tfrac{1}{2}(p+dp)\mathrm{S}z_0+\left(p+\frac{dp}{2}\right)\mathrm{S}\,dz, \quad . \quad . \quad (1)$$

where V_1 is the virial depending on intermolecular actions, and ϖ is the weight of matter contained in the elementary cylinder. Since, as indicated by the author, the values of W and V are independent of the position of the coordinate axes, and in particular of the value of z, it follows that the coefficient of z_0 in the expression (1) equals zero; whence

$$\tfrac{1}{2}\varpi+\tfrac{1}{2}p\mathrm{S}-\tfrac{1}{2}(p+dp)\mathrm{S}=0,$$

which gives

$$dp = \varpi/\mathrm{S}.$$

Ultimately it is shown by some simple manipulations that

$$W = V_1 + \nu\left(p + \frac{dp}{2}\right), \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where ν equals $S dz$, *i. e.* the volume of the cylinder.

The paper concludes with a consideration of the Isothermals of a Perfect Gas having Weight. The author takes a fixed weight ϖ, as small as possible, contained in the elementary cylinder already described; W is a constant; $V_1 = 0$; and (2) can be put in the form

$$\nu = \frac{2W}{3\left(p + \frac{1}{2}\frac{\varpi}{S}\right)};$$

from which equation, inasmuch that for a fixed value of p ν is not definite, for it depends on the section S, the conclusion is drawn that, rigorously, a heavy gas has not a definite isothermal. A. Gs.

---

609. *Algebraical Machines.* **L. Torres.** (C. R. 121. pp. 245–248, 1895.)—Considering an equation of which all the variables may have imaginary values, each variable A being really a function of two others, its modulus a and its argument α, one may represent it by two moving parts. One method described in the paper is carried out by means of the following mechanism:— Two parallel shafts carry gear-wheels, one large and one small, on each shaft; each large one being in the plane of, but not in gear with, the small wheel on the other shaft. The gearing is effected by an idle wheel, sliding and turning upon a third shaft parallel to and between the two others. So far, either one pair of wheels or the other are in gear with the idle wheel, and one shaft drives the other at one of two different speeds. But between the two wheels on each shaft a spiral fusee is cut, with a uniform screw pitch, and with a generating radius diminishing from that of the large wheel to that of the small wheel. The edge of this fusee is cut with teeth of the same pitch as that of the gear-wheels, and is continuous with them. In the equation

$$V_e = \log[10^{U_e} + 1] + mU_e$$

the idle wheel gears with one pair of the end wheels when $U_e < -J$, and with the other pair when $U_e > +J$, giving in the first case the speed-ratio m, and in the second case $m-1$. While U changes from the value $-J$ to $+J$, the idle wheel runs over the intervening spirals, giving the speed-ratio $\frac{10U_e}{10^{U_e}+1} + m$. The passage of the idle wheel over the spiral to the end wheels and back is controlled by the last wheel of a counter, which makes one revolution while the fusee makes hundreds or thousands. Many equations may be represented in a single machine. A machine was presented, with

the paper, to the Academy, which calculated, with a relative error of $\frac{1}{100}$, the real roots of the equations

$$x^9+Ax^8-B=0 \quad \text{and} \quad x^9-Ax^7+B=0.$$

A. P. T.

---

610. *Laws of Friction.* **P. Painlevé.** (C. R. 121, pp. 112–115, 1895.)—On forming the equations of motion of bodies subjected to friction it is found that, when the friction is considerable, for certain initial conditions the equations are satisfied by several different motions, whilst for other initial conditions they are incousistent. The author investigates this mathematically for a few cases, and concludes that the ordinary laws of friction are logically inadmissible when the friction is great. J. W. C.

---

611. *Osmotic Phenomena between Ether and Methyl Alcohol across various Membranes.* **F. M. Raoult.** (C. R. 121. pp. 187–189, 1895.)—When the two compartments of an osmometer are filled with two different liquids there is, in general, osmosis—*i. e.* a passage of liquid through the permeable wall. When ether and pure methyl alcohol are used, with a diaphragm of pig's bladder, the following flow of liquid may be observed:—

(*a*) From the pure methyl alcohol to the pure ether;
(*b*) From the pure methyl alcohol to a mixture of $\frac{1}{5}$ ether and $\frac{4}{5}$ methyl alcohol;
(*c*) From such a mixture to the pure ether.

It appears, then, that the bladder is impermeable to ether, and that the rapidity of flow is in inverse proportion to the quantity of ether mixed with the alcohol. Across a diaphragm of vulcanised caoutchouc 1 millimetre thick osmosis occurs quite as energetically as with pig's bladder, but always in a contrary direction. The effects detailed above are all reversed; so that the vulcanised rubber appears to let through ether, but not methyl alcohol. To measure the pressure which can be obtained by this osmosis is difficult, because such large pressures can be obtained. In one experiment 50 atmospheres was obtained before the apparatus broke down. The experiments show (1) that the osmosis between two given liquids not only varies much in rapidity but also changes in direction when different membranes are used, and (2) that the osmotic passage of substances across a diaphragm must be absolutely independent of the molecular weight and of the character of the substances dissolved or of the solvents. S. S.

---

612. *Muscular Energy of Positive and Negative Work.* **A. Chauveau.** (C. R. 121. pp. 91–97, 1895.)—The author has established that positive work (lifting a load) heats the muscles more than negative work (lowering the load). The figures of three series are:—Negative work 0°·095, 0°·093, 0°·239: positive 0°·108,

0°·121, 0°·310: the ratios 0·88, 0·77, 0·77. He now treats the energy-problems graphically, and mentions that observations of the work of respiration entirely confirm his views, but he does not enter into any explanations. In the case of positive work, the muscular energy which creates the physiologic elasticity is entirely derived from the then more active chemical processes. Negative work requires less energy, inasmuch as the destroyed mechanical energy helps. The muscular elasticity created by dynamic contraction has two things to do when a load is to be lifted: to maintain the equilibrium at all positions, and to raise the load from position to position. The energy of the first process is always half of the energy required to support the body at the maximum height to which it is raised by dynamic contraction—that is, half the static energy. To this is to be added the energy of the second process—raising the load. In the case of negative work the latter energy is to be deducted; the first term remains the same. H. B.

---

613. *Maxwell's Theory of Movement of Pure Ether.* **H. v. Helmholtz.** (Wied. Ann. 53. pp. 135–143, 1894.)—In this paper motion produced in the ether under the Maxwellian system of stress is considered. If α, β, γ be the component velocities at any point of the ether considered as an incompressible fluid, then the quantity called in a previous paper the electrokinetic potential is represented by the expression

$$\iiint S\left[\frac{\partial\alpha}{\partial x}+\frac{\partial\beta}{\partial y}+\frac{\partial\gamma}{\partial z}\right]dx\,dy\,dz,$$

where S is a function of the coordinates and remains constant, since by the equation of continuity the quantity in brackets is zero. If (X, Y, Z)(L, M, N) be the electric and magnetic forces according to the specification of Hertz, then the components of electric stress in the medium are, according to Maxwell's theory,

$$\Xi_e=\frac{1}{4\pi}\left\{Y\left(\frac{\partial X}{\partial Y}-\frac{\partial Y}{\partial X}\right)+Z\left(\frac{\partial X}{\partial Z}-\frac{\partial Z}{\partial X}\right)\right\},$$

$$\Upsilon_e = \quad \&c. \quad \&c.,$$

$$Z_e = \quad \&c. \quad \&c.$$

Magnetic stresses Ξ_m, Υ_m, Z_m are given by precisely similar expressions, so that the total stress-components are

$$\Xi=\Xi_e+\Xi_m,\quad \Upsilon=\Upsilon_e+\Upsilon_m,\quad Z=Z_e+Z_m.$$

The quantities $\partial Y/\partial Z-\partial Z/\partial Y$ in the above equations correspond to components of the forces which are not derivable from a potential, and are hence called cyclic forces. If we write the system of equations,

$$\frac{\partial y}{\partial z}-\frac{\partial z}{\partial y}=-4\pi\mathrm{A}\frac{d\mathrm{L}}{dt},\quad \&c.\quad \&c.,$$
$$\frac{\partial \mathrm{N}}{\partial y}-\frac{\partial \mathrm{M}}{\partial z}=-4\pi\mathrm{A}\frac{d\mathrm{X}}{dt},\quad \&c.\quad \&c.,$$

where

$$\frac{d\mathrm{X}}{dt}=\frac{\partial \mathrm{X}}{\partial t}+\frac{\partial}{\partial y}\{\mathrm{X}\beta-\mathrm{Y}\alpha\}+\frac{\partial}{\partial z}(\mathrm{L}\gamma-\mathrm{N}\alpha),$$
$$\&c.\qquad \&c.\qquad \&c.,$$
$$\frac{d\mathrm{L}}{dt}=\frac{\partial \mathrm{L}}{\partial t}+\frac{\partial}{\partial y}(\mathrm{L}\beta-\mathrm{M}\alpha)+\frac{\partial}{\partial z}(\mathrm{L}\gamma-\mathrm{N}\alpha),$$

the total stresses and components become

$$\Xi=\mathrm{A}\left\{\mathrm{Z}\frac{d\mathrm{M}}{dt}-\mathrm{Y}\frac{d\mathrm{N}}{dt}+\mathrm{M}\frac{dz}{dt}-\mathrm{N}\frac{d\mathrm{Y}}{dt}\right\};$$

or, if for shortness we put

$$\mathfrak{P}=\mathrm{ZM}-\mathrm{YN},\quad \mathfrak{Q}=\mathrm{XN}-\mathrm{ZL},\quad \mathfrak{R}=\mathrm{YL}-\mathrm{XM},$$

the stresses are given by

$$\Xi=\mathrm{A}\frac{\partial \mathfrak{P}}{\partial t},\quad \Upsilon=\mathrm{A}\frac{\partial \mathfrak{Q}}{\partial t},\quad \mathrm{Z}=\mathrm{A}\frac{\partial \mathfrak{R}}{\partial t}.$$

Thus, only if the distribution of electricity is of such a nature as to cause a flow of energy in the ether, are there ponderomotive forces in the ether which are not counteracted by incompressibility, and in this case the ether must be set in motion. The electromagnetic disturbances once set up propagate themselves with the velocity of light. The quantities $\mathfrak{P}$, $\mathfrak{Q}$, $\mathfrak{R}$ are ordinarily of the second order of magnitude, and in light oscillations are vanishingly small; so the forces which arise from them are vanishingly small also of the second order.

The electric equilibrium, when disturbed, is restored with great rapidity; but in free ether those electric and magnetic distributions which give rise to cyclic forces which cannot be equilibrated by pressure must call forth motion of the ether, and this will go on increasing until the electric and magnetic forces induced by the motion have annulled the ponderomotive forces. The next inquiry of the paper is whether such motions can in every case be found in the ether as will annul the ponderomotive forces not annulled by incompressibility. The forces annulled by the pressure of an incompressible fluid are of the form

$$\Xi_p=-\frac{\partial \mathrm{P}}{\partial x},\qquad \&c.,\qquad \&c.,$$

and the conditional equations which must be fulfilled in order that the cyclic forces in the free ether may be equilibrated, are the three:

$$\frac{\partial \mathrm{P}}{\partial x}+\mathrm{A}\left\{\frac{\partial \mathfrak{P}}{\partial t}+\beta\left(\frac{\partial \mathfrak{P}}{\partial y}-\frac{\partial \mathfrak{Q}}{\partial x}\right)-\gamma\left(\frac{\partial \mathfrak{R}}{\partial x}-\frac{\partial \mathfrak{P}}{\partial z}\right)\right\}=0,$$

&c. &c. &c.,

&c. &c. &c.,

and the equation of continuity. Elimination of α, β, γ gives

$$\left(\frac{\partial \mathrm{P}}{\partial x}+\mathrm{A}\frac{\partial \mathfrak{P}}{\partial t}\right)\left(\frac{\partial \mathfrak{Q}}{\partial z}-\frac{\partial \mathfrak{R}}{\partial y}\right)+\left(\frac{\partial \mathrm{P}}{\partial y}+\mathrm{A}\frac{\partial \mathfrak{Q}}{\partial t}\right)\left(\frac{\partial \mathfrak{R}}{\partial x}-\frac{\partial \mathfrak{P}}{\partial z}\right)$$
$$+\left(\frac{\partial \mathrm{P}}{\partial z}+\mathrm{A}\frac{\partial \mathfrak{R}}{\partial t}\right)\left(\frac{\partial \mathfrak{P}}{\partial y}-\frac{\partial \mathfrak{Q}}{\partial x}\right)=0.$$

From this equation P can be found, if the functions $\mathfrak{P}$, $\mathfrak{Q}$, $\mathfrak{R}$ of x, y, z, t are given.

The conditional equations give each two of the quantities α, β, γ in terms of the third, so that the direction of the stream-lines is determined; and since the product of the resultant velocity into the cross section of each narrow tube of flow is constant, the components of flow are all given if their resultants are given for all points in the plane $x=\text{const.}$ The complete integral of the conditional equations can be constructed from any one particular integral of the system of equations, and the general integral for the case of

$$\partial \mathfrak{P}/\partial t=0, \quad \partial \mathfrak{Q}/\partial t=0, \quad \partial \mathfrak{R}/\partial t=0.$$

If the last-written equations hold, we have

$$\alpha\frac{\partial \mathrm{P}}{\partial x}+\beta\frac{\partial \mathrm{P}}{\partial y}+\gamma\frac{\partial \mathrm{P}}{\partial z}=0,$$

and the stream-lines lie in the surface $\mathrm{P}=\text{const.}$ Also the lines of which the equations are

$$dx : dy : dz = \partial \mathfrak{Q}/\partial z-\partial \mathfrak{R}/\partial y, \quad \&c.,$$

lie in the same surface.

In certain circumstances there will be slipping of the ether at the surfaces of the bodies. This may be regarded as a very rapid transition in value of the tangential velocities taking place in a thin boundary layer, where also there is a corresponding rapid transition in the value of the tangential components of the electric and magnetic forces. A. Gy.

LIGHT.

614. *Comparison of the Spectra of the Gas from Clèveite and of the Solar Atmosphere.* **H. Deslandres.** (C. R. 120. pp. 1112–1114, 1895.)—A spectroscopic tube closed by a quartz plate was arranged so as to receive the gases evolved from clèveite when heated or brought into contact with sulphuric acid. Before heating, the air in the tube showed some of the lines of argon; on heating to 300°, there was a copious evolution of an oxy-compound of carbon, apparently produced by the dissociation of some compound. On placing the clèveite in contact with the acid, the ray D_3 appeared for the first time, accompanied by other intense lines both visible and ultra-violet. The author has determined the wave-lengths and intensities of these rays: he finds that the lines of wave-lengths 587·6 (D_3) and 447·18 are coincident with lines always present in the spectrum of the sun's chromosphere, but their relative intensities in the sun and in clèveite gas are not the same. Altogether 20 lines were recognised in the clèveite spectrum, of which 13 have been observed from time to time in the solar chromosphere by the author or Young. Several rays were fairly intense in clèveite, notably λ 501·6 and λ 388·88, which occur in only 25 to 30 per cent. of the observations of the sun's spectrum, and then only as faint lines. The author therefore considers clèveite gas to be a mixture or a compound, and is strengthened in his opinion by an observation that the line D_3 never occurs at the negative pole, while λ 501·6 is there very visible. J. L. H.

---

615. *Colour Photography by Absorption-Colours, and Mechanical Colour-Selection in Nature.* **O. Wiener.** (Wied. Ann. 55. pp. 225–281, 1895.)—Zenker, in his 'Lehrbuch der Photochromie,' 1868, first attributed the colours as photographed on a medium to a periodic structure in that medium, produced by stationary light-waves—an explanation which was confirmed by Lippmann's experiments in 1891. However, in 1871, Schultz-Sellack raised some objections to the theory, as being inapplicable to the methods of Seebeck and Poitevin, and also to his own; and as these objections seemed worthy of further notice, the author undertook the experiments detailed below to bring the matter to a satisfactory conclusion. Schultz-Sellack questioned the possibility of obtaining regular stationary waves in powders, or where the sensitive film is not backed by a reflecting surface; Seebeck having employed in 1810 a damp powder of silver chloride, and Poitevin having sensitised paper by immersion in various solutions. [For the future these two methods will be designated as "old."] In the case, however, of Becquerel's method, where a transparent film was formed on silvered plates, the objections could have no weight. Schultz-Sellack brings forward the alternative theory of

mechanical subdivision of the sensitive layer to varying extents, depending, not on the colour, but on the effective intensity of the incident light. The colour-reproduction would be consequently purely accidental. This theory is shown later to be false. The possibility of the colours being other than interference-colours is suggested by Carey Lea's production of coloured substances from the haloid salts of silver by purely chemical means; also by some experiments of Krone on Poitevin's method, pointing to a similar result. It would seem, therefore, that the results of Lippmann and Becquerel's methods were essentially different from those of Seebeck and Poitevin—the old methods,—the former producing interference-colours and the latter actual or absorption-colours ("Körperfarben"); and the following experiments support this view.

If Lippmann's gelatine plates be moistened by a steam-jet, the colours change rapidly to those of longer wave-length, owing to the expansion of the gelatine increasing the distance between the interference-layers. This does not take place on treating similarly the films of the old methods. To distinguish further between the interference- and absorption-colours, the spectrum was divided along its length into two portions, which were illuminated with rays of different angles of incidence; obviously the greater the angle of incidence, the longer distance, as measured in the direction of the ray, is there between the interference-layers, assuming these to exist, and the nearer is the apparent colour to the red end of the spectrum. Thus the two portions of the spectrum would, in the case of interference-colours, appear shifted relatively to one another. This double illumination was brought about by placing a right-angled prism with its hypotenuse resting on the plate so as to cover half the spectrum, the space between the two being filled with benzol to prevent total reflection. The light falling on the plate at an angle of 45° enters the prism perpendicularly to its surface, and after refraction enters that portion of the film lying under the prism at a smaller angle of incidence. A mark is made along, say, the sodium line, and the observer looks at this in the direction of the surface of the prism, so that he can see simultaneously the two portions of the line through the prism and outside it. The portion of the sodium line seen through the prism would, in the case of interference-colours, appear shifted towards the red. Both Lippmann's and Becquerel's plates, when observed under these conditions, showed a considerable shifting of the spectrum, amounting to about 2 mm. In attempting to observe similarly films of the old methods, certain difficulties arose. Seebeck's plates consist of chloride-of-silver powder pressed between two glass plates; owing to the total reflection which would take place at the surface of the glass and air, the method could not be employed without the introduction of benzol, which, however, could not be effected without disturbing the powder. The powder was therefore mixed with collodion and allowed to set upon glass, and the film so obtained observed as before. In this

case no shifting of the spectrum could be seen, nor again in the case of Poitevin's paper sheets.

A further proof of the colours on Becquerel's plates being due to interference is afforded by stripping the film from its silvered support, and viewing it from the back. The spectrum appears very considerably shifted from its position when regarded from the front, and the colours are changed in tone. Such a change would be inconceivable with absorption-colours, and could be explained only by interference. Want of space prevents the author from giving the explanation of this phenomenon here. A similar effect was observed in Lippmann's plates, and accounted for in a way which is, in the author's opinion, erroneous. Applying the same test to the films produced by the old methods, which are transparent enough to be viewed from the back, the colours appear in exactly the same position when seen from either side. Also they appear identical in transmitted and reflected light, which is indeed another proof that the latter colours are due to absorption; for in the case of pure interference the colours seen by transmitted and reflected light must necessarily be complementary.

These foregoing experiments leave no room for doubt that the Lippmann and Becquerel plates owe their colours to interference, while in the old methods actual absorption-colours are produced. It would appear natural, however, that the absorption-colours produced in Seebeck's plate were also produced in Becquerel's, the sensitive substance in the two being chemically almost identical. Yet with clearly defined interference-colours they would not be noticeable; but were the exposure lengthened the nodes of the stationary light-waves would spread, making the interference-colours weaker and the absorption stronger. To test this a Becquerel plate was exposed for 30 hours. With this the prism-experiment gave a hardly appreciable shifting of the spectrum, and also the film, when stripped from the support and viewed from the back, showed the colours in the same position. It is therefore clear that there are absorption-colours produced as in Seebeck's plates, and that they play the more important part the longer the exposure. It remains to consider the sensitive substances and their action. The plates were exposed to the light of an electric arc with 23 mm. carbons; the time of exposure to this was in most cases from one-half to one hour, though under favourable conditions colours appeared after a few minutes. For producing Seebeck's plates, pure chloride-of-silver powder was precipitated and dried in the dark, and finally introduced between two glass plates, whose edges were then cemented together. The plate was then given a preliminary exposure to violet or white light until coloured a dark violet. For Becquerel's process a copper plate silvered and polished was put as positive electrode in dilute hydrochloric acid (1 : 8), and a current of 2–4 amperes for a surface of about 30 sq. cms. passed for a few seconds. The plate was then dried and rubbed with a soft leather. In the preparation of Poitevin's paper, Rives rough paper was immersed for two minutes in a 10-per-cent. salt solution,

then for one minute in an 8-per-cent. solution of silver nitrate; after rinsing, it was exposed to daylight while in a solution of 5 grm. stannous chloride in 100 c.c. of water till fairly dark, when it was dipped in a mixture of one part saturated potassium bichromate and two parts saturated copper-sulphate solution, and then dried. No development is required with any of these processes. With regard to the sensitive substance, Guntz has lately shown that a subchloride is formed on exposing silver chloride to light. Pure unexposed silver chloride is sensitive only to violet and ultra-violet light; however, after a preliminary exposure the mixture of chloride and subchloride is sensitive to all colours of the spectrum. It was found that chemically prepared subchloride was sensitive in the same way as the mixture to all colours. Becquerel's plate consists of silver chloride with a very small proportion of subchloride. As to the comparative merits of the various methods, Becquerel's gives bright and accurate colours, as does Lippmann's, and is far superior to either Seebeck's or Poitevin's. Seebeck's plates show clearly only violet, blue, and red; green is far from clear, and yellow generally absent. Poitevin's give better results; all the colours appear, though often with a uniform yellow-brown tinge. Lippmann's image has the advantage over Becquerel's of greater sensitiveness, and of being capable of fixation; but the colours change considerably with the angle of incidence and cannot be seen in diffused light—neither of which defects are possessed by Becquerel's plates, owing to the high index of refraction.

The theory of Schultz-Sellack, mentioned above, demands some notice. He formed a transparent layer of iodide of silver, by iodising a silver deposit on glass. This, says Schultz-Sellack, cannot be chemically changed, as the iodine has no absorbent; the change on exposure is therefore mechanical, the surface being reduced to a fine powder, visible under the microscope. That the cause of the colours here is different from that in the old methods is shown by a change of colour consequent on a change in the angle of the incident light. Again, Schultz-Sellack's statement that the different colours are produced by differences in the intensity and duration of the illumination, and not by differences in the colour, is inapplicable to the old methods. A test applied to each of the films showed that during the exposure red first made its appearance, but suffered no change in colour, and the other colours appeared later in their proper places; whereas, were the above theory correct, one colour would first appear over the whole spectrum, changing gradually to the other colours in corresponding positions. It is therefore to be concluded that Schultz-Sellack's explanation of the colour-reproduction by the old methods is incorrect.

The ideal sensitive substance for reproducing colours by absorption should have the following properties:—Since the reproduction of colour depends on the change in the substance consequent on absorbing the coloured light, the sensitive substance must be uniformly absorptive for all colours, and must give at least three products of the action of light possessing primary colours, and

besides, white, though the latter only in a slight degree. Also, any colours so formed must be sensitive to light, so that any mixture of the primary colours may be reproduced; obviously any colour cannot be sensitive to similarly coloured light, since it does not absorb it. The original colour of the substance must be black; otherwise this will not be reproduced. White will be given by the combined action of all the colours. Such a substance would reproduce accurately all colours within certain limits of exposure, beyond which white would predominate and cause the colours to fade. The above characteristics seem very involved, but are nevertheless derived from the actual characteristics of the imperfect processes at present known. In the old methods the first imperfection is that the fundamental substance is not black, but is in Seebeck's dark violet to grey-violet, and in Poitevin's dark grey-violet to grey-brown; these tones therefore take the place of black. The coloured products of the action of light are, from Carey Lea's and Krone's researches, of great number or of great variety of colour. They have the disadvantage, however, of not being pure simple colours, which accounts for the inexact reproduction of the tones. There exists, too, in Seebeck's method no white product, so that this cannot be reproduced; it does exist, however, and is produced in Poitevin's—also only with difficulty, so that the colours fade only after a very long exposure.

To test the action of different lights on the coloured products the following experiment was made:—A spectrum was thrown on to the spectrum-image on the film but crossing it, the lines of the two spectra being at right angles. Under the red of the second illumination the red only of all the colours of the image was unaltered; all the other colours took a red tinge. And the same can be said of the other colours, though these, being not clearly impressed on the image, were still less so after the second illumination. The same experiment was carried out with a better result on a Poitevin paper; and it may be concluded that, in general, each coloured substance remains unaffected only by the similar-coloured light, and is changed under other lights. One exception, however, arises: the yellow or, rather, orange colour which is produced by a yellow illumination is not changed by a red or a green light, and only slightly by a blue, and is therefore to a great extent insensitive to light. By a short exposure to a sodium-flame, first a red, which later changed to an orange-coloured product, was formed. The sensitive substance therefore, in Poitevin's method, departs from the ideal conditions in not reproducing the yellow colour accurately; and consequently the false product also, as might be expected, does not follow the ideal conditions.

As a conclusion from the foregoing results it may be stated that colours are reproduced in photography by a process of colour-selection ("Farbenanpassung"); that coloured substance remaining under each coloured light which can best withstand the continued action of that light, and this is the substance of similar colour to the light. A very similar colour-selection appears to obtain

in nature, and the changes of colour there observed are worthy of notice here. When Darwin's theory of natural selection began to play so important a part in accounting for all changes in animal and vegetable structure, adaptation of the colour of animals to that of their surroundings was attributed to the same process, and any immediate effect of light on the colour of the skin or hair was lost sight of. That there is such a direct effect is nevertheless conclusively shown by the rapid changes observed, for instance, in the colours of chrysalides and caterpillars—changes first noticed by Wood, and afterwards dealt with very fully by Poulton. Wood attributes the change of colour to a photographic sensitiveness of the skin, but gives no proofs in support of the supposition. In the case of fishes and frogs the change of colour is due to an alteration in the disposition of the colour-bearing cells—the so-called chromatophora. The power of changing colour is, however, lost with the removal of the eyes. Poulton, in endeavouring to find a similar behaviour among caterpillars, covered the eyes with an opaque screen and also removed the horns, thinking that these might possibly be the seat of a sensitive organ. Their power of changing colour was nevertheless in no way diminished: it must therefore reside in the skin. The skin of *Amphidasis betularia*, a caterpillar capable of changing colour to a marked degree, owes its green colour to a substance in the layer of fat between the epidermis and surface-muscles. The epidermis itself can contain a dark-coloured matter which, hiding the green, gives a brown colour to the skin. The change in this instance is not due to a different arrangement of the fixed colour-cells, but an actual alteration in the colouring-matter under the action of light. The principal changes take place in the dark substance in the epidermis, though the green below is also affected. The biological explanation of these colours as protective to the animal appears to be contradicted by the colours being not only those of the natural surroundings, but others which cannot be considered as such. Thus Morris succeeded in producing white, red, salmon, black, and blue pupæ of *Danais chrysippus*, which are only green or pink in nature. Nevertheless it is not to be denied that natural selection may have been instrumental in forming such a sensitive colouring-matter—one indeed approaching closely to the ideal colour-sensitive substance mentioned above. How close this similarity is may be seen from a further conclusion of Poulton's: that the surroundings determine not only the presence or absence of the pigment in the epidermic cells, but also its constitution and therefore colour when present. Against the similarity must, however, be mentioned the following experiment by Poulton:—The caterpillar, when illuminated by lights of two different colours, did not become parti-coloured, but of a uniform colour of average tone. But his hypothesis that the colour was distributed by the action of the nerve network would remove the objection this brings against the colour-sensitive nature of the substance in the skin. That a certain relation exists between these substances and those used

in colour-photography seems evident. Nor does such a relation necessarily interfere with the theory of natural selection as applied here; for those individuals would best be protected from destruction whose skin was most sensitive to colour. Finally, therefore, it may be said that as in photography those colours are selected by each coloured light which can best withstand the continued action of that light, viz. the corresponding colour, so a similar mechanical selection gives rise to the changes observed in nature. G. H. B.

---

616. *Theory of the Perception of Colours.* **G. Darzens.** (C. R. 121. pp. 133–135, 1895.)—The theory supposes that the retina behaves very much like Lippmann's well-known films, and that interference effects are produced in the neighbourhood of the rods and cones. The rods are supposed to be acted on indifferently whatever the wave-length, and so to detect light but not indicate the colour; the cones, being of unequal lengths, will be acted on differently according to the wave-lengths. The theory is supported by the observations that at the yellow spot, where colour-delicacy is very great, the cones are abundant; that nocturnal animals, which do not trouble about colours, have no cones; and that birds which live on coloured insects have many cones. The theory is brought into accord with the hypothesis of Young and Helmholtz by supposing that the cones can be divided into three groups connected with three centres of perception. A. Gs.

---

617. *Photography in Natural Colours.* **R. Neuhass.** (Verh. Phys. Ges. Berlin, 14. pp. 18–24, 1895.)—Up to now a grainless film has been considered a *sine quâ non* in colour-photography; nevertheless Valenta's and Lumière's plates, which reproduce colours excellently, show grains about the length of half a light-wave, their size being increased in development by about five times. Under these circumstances it seems questionable whether interference layers can exist. Other facts, too, contradict Zenker's theory. Lengthening the exposure changes the colours to those of longer wave-length, and rubbing the plate with alcohol has the contrary effect, whereas, following Zenker's theory, it should merely weaken the colours by removing some of the layers. However, a direct proof of the existence of interference layers was afforded by examining a transverse section of the film under the microscope, when the striated structure could be resolved. In the author's experiments considerable differences presented themselves in images formed under the same conditions; and these led the author to the conclusion that the images were sometimes on the surface and at other times in the substance of the film. However, no satisfactory explanation could be brought forward to account for this difference. G. H. B.

---

618. *Colour Perception.* **H. W. Vogel.** (Wied. Ann. 54. pp. 745–751, 1895.)—Some years ago the author published the results of some experiments showing how uncertain and how dependent on circumstances is our idea of colour. This is most marked in considering complementary colours. Thus, one coloured light can be complementary to many others, as white indeed is to all simple colours; also, those colours generally looked on as complementary—red to green, sulphur-yellow to cobalt-blue, &c.—are so only in the presence of white light. Further, the idea that light of a certain wave-length gives a fixed colour-impression is entirely false; our estimate of the colour is widely influenced by the brightness. For instance, the region of the F line appears in weak light green, while in strong light clear blue; the region of the G line is by weak light violet, by strong blue, and by strong sunlight bluish white. Helmholtz, in his 'Physiologische Optik,' realizes our inability to judge colours absolutely. He says:—"The colour of full sunlight is taken to be white; small deviations from this are quite inappreciable to us, unless we have the means of a direct comparison; without this, our idea of white is most uncertain." He caused also the gold-yellow of the spectrum to appear brown by contrasting it with clear white light. It is evident, therefore, that the only means of determining a colour is by comparison with another. Helmholtz considers the matter in this way:—In estimating the colour of a surface, we have always a tendency to separate the colour of the illumination from that of the surface. Thus, if in a combined illumination of candle- and daylight, which gives a white-reddish-yellow colour, a shadow is formed excluding the candle-light, we subtract the reddish-yellow from the colour of the shadow and regard this as blue, whereas in reality it is white. This is the same as saying that the proximity of the reddish-yellow ground-colour enables us to realize in the candle-shadow the want of reddish yellow, and we therefore judge it as blue. Similarly, we call a surface yellow when we realize the want of blue rays, and red when we realize the want of green rays, and so on. When colour-perception is considered from this standpoint, the explanation of some peculiar results which the author obtained with mono- and dichromic light is at once clear. The experiments were as follows:—In monochromic light all traces of colour disappear from pigments, and merely gradations of black and white are visible. A blue pigment under blue light appears white, but is clearly blue on the addition of a yellow light. Under a combined blue-and-red illumination, yellow and red are hardly distinguishable; under red and green light, however, red appears as red, and yellow as pale yellow. That red and yellow pigments both appear as yellow under the double illumination, though this possesses no yellow rays, is due to the fact that both pigments reflect blue but slightly; wherefore one realizes the want of blue rays in each, and consequently considers each as yellow. That the pigments are distinguished on

substituting green for blue in the illumination is explained by the green rays making the lack of green in the red apparent, and therefore making it appear red. With the yellow pigment it is different: this reflects both green and red, and (according to Helmholtz) the mixture of these produces pale yellow. That a blue pigment appears white in blue light, and blue only on addition of a yellow, is not, as would appear at first sight, due to the presence of contrast-colours of blue and yellow, for these exist only in white light; but the explanation lies in the fact that the want of yellow rays is realized only with yellow illumination, and this want must be apparent before the pigment appears blue. By reasoning similar to the above, all such phenomena of colour-perception may be explained. G. H. B.

HEAT.

619. *Mercury Thermometer Corrections.* (Extracted by C. E. Guillaume from 'Zeitschrift für Instrumentenkunde,' vol. xiv. p. 305. J. Phys. 4. p. 324, 1895.)—The following formulæ give the correction, t_m being the mercury-thermometer reading and T_N the nitrogen-thermometer reading :—

From 0° to 100°,

$$t_m - T_N = t_m(100 - t_m)(21{\cdot}51 - {\cdot}2638\,t)\,10^{-6}.$$

From 100° to 300°,

$$t_m - T_N = t_m(100 - t_m)(49{\cdot}82 - {\cdot}4259\,t)\,10^{-6}.$$

J. W. C.

---

620. *Mirage Effects in Natterer's Tubes.* **P. Villard.** (C. R. 121. pp. 115–118, 1895.)—The author employs a tube of ethylene containing a small thermometer at each end. This tube is placed in ice till the whole is at 0° and part of the ethylene is liquefied. If it is then placed in water at 11°, the level of the liquid gradually becomes indistinct, showing a continuous change in the density and refractive index of the ethylene. At this stage the thermometers invariably register different temperatures, the upper one reading as much as a degree higher than the lower one; and they do not come to the same temperature till the contents of the tube are homogeneous. A layer of rapidly varying density can be produced in a tube above the critical temperature by gently warming one end with the hand. The author ascribes the appearance of mirage to the difference of temperature, and points out that since the density varies most rapidly with the temperature at the critical point, the mirage will be most noticeable at a layer which has the critical temperature. J. W. C.

SOUND.

621. *Velocity of Sound.* **Aignan** and **Chabot.** (J. Phys. 4. pp. 321–323, 1895.)—A harmonium reed is mounted on the upper end of a glass tube, whose length can be varied by allowing water to flow in by the lower end. The reed can only be made to sound when the length of the pipe is an odd multiple of half a wave-length, and the velocity of sound is calculated from the pitch of the reed and the distance between two such positions. The apparatus is designed for use in lectures. J. W. C.

---

622. *Two Graphic Methods of Counting Beats, and a Microphonic Capsule.* **F. Campanile.** (N. Cim. 4. 2. pp. 373-376, 1895.)—(1) The interfering waves are led down a single tube to a Marey drum, the oscillations of which are registered by Duhamel's method. Each wave is caused by the vibrations of a membrane placed in the wall of a sounding-pipe near a node. This method is, however, of very limited application—viz., to two pipes or a pipe and a resonator excited by a fork, and for tones scarcely higher than ut_3. —(2) The Marey drum is replaced by a caoutchouc membrane forming the bottom of a brass chamber, which is loosely packed with bits of retort-carbon and has an insulated cylinder of retort-carbon passing through its top. The oscillations of the membrane cause variations in an electric current which passes between the cylinder and the chamber, and these variations act on a relay by means of which they are registered. This is a very sensitive method. The shape of the curves obtained depends on the motion of the vibrating armature, the action of the spring, and the magnetic action of the core. R. E. B.

ELECTRICITY.

623. *Radiation of Electromagnetic Energy in Space.* **K. Birkeland.** (Wied. Ann. 52. pp. 357–380, 1894.)—The author first recalls Poynting's expressions for the flow of energy in a medium, and gives the name of radiation-vector ("Strahlenvector") to the expression

$$J = EH \sin (EH)/4\pi A,$$

which is the rate of flow of energy per unit of area across the plane of EH, in the direction in which a right-handed screw would move if turned round, through the smallest angle, from the direction of E positive to that of H positive. He then considers the possibility of finding some mode of verifying the expression, remarking that no ordinary measurements of energy can contradict the theory, since they all involve the consideration of variations of amount of energy within a closed surface, and the point to be verified is the legitimacy of dividing-up the total flow through the closed surface into the flow across each elementary element of surface expressed by the radiation-vector. The author then discusses the composition of radiation-vectors, noting, what of course is obvious, that the radiation-vector due to two pairs of electric and magnetic forces E_1, H_1 and E_2, H_2 is not

$$E_1H_1 \sin (E_1H_1)/4\pi A + E_2H_2 \sin (E_2H_2)/4\pi A,$$

and that in the general case the electric and magnetic forces must be compounded separately, and the two resultants E, H used to form the vector. He then remarks (as has been done, in fact, by other writers) that the most general flow of energy possible is got by adding to the surface-integral another, namely,

$$\int (B\,dy\,dz + C\,dz\,dx + D\,dx\,dy),$$

where B, C, D are of proper dimensions and fulfil the condition

$$\partial B/\partial x + \partial C/\partial y + dD/dz = 0$$

for every point in the space considered, so that this additional surface-integral vanishes. The most general form of radiation-vector is then taken to be the vector the components of which are

$$J_x = (B + NY - MZ)/4\pi A,$$

$$J_y = \quad \&c. \quad \&c.,$$

where L M N, X Y Z are the components of the magnetic and electric intensities.—The discussion of the question as to what choice from the infinite number of possible values of (B, C, D)

is to be made, leads, as may readily be supposed, to no definite answer. The author comes to the conclusion that, in order that a mechanical definition of the radiation-vector may be framed, we must know exactly the whole "inneren Mechanik" of the electromagnetic field, and that the mechanical conception of energy-radiation is inseparable from the notion of potential energy. If we were in a position to regard all energy as kinetic, we might be able to give a mechanical definition of energy-radiation.

The rest of the paper is concerned with the proposition that, if the most general form of the radiation-vector as defined above is only a function of the electric and magnetic forces, without any additive constant, Poynting's form of the radiation-vector is the only one in agreement with Maxwell's equations. A. Gy.

---

624. *Ponderelectromotive Forces due to Variations of Electrostatic Energy.* **N. Schiller.** (Wied. Ann. 53. pp. 432–446, 1894.)—The object of the paper is the deduction of the electric ponderomotive forces given by the theories of Maxwell, Helmholtz, and Kirchhoff. The electric energy W is given by the equation

$$W = \iiint \frac{K}{8\pi} \left\{ \left(\frac{\partial\phi}{\partial x}\right)^2 + \left(\frac{\partial\phi}{\partial y}\right)^2 + \left(\frac{\partial\phi}{\partial z}\right)^2 \right\} dx\,dy\,dz,$$

ϕ denoting the electric potential and K the dielectric constant supposed a function of the coordinates x, y, z. A continuous medium is supposed to occupy the field, and to be so connected with the bodies considered that the displacements of the latter are determined by corresponding changes of the elements of the medium. The variation δW produced in W by a motion of the medium whereby the coordinates x, y, z of a point in it are changed to $x+\partial x$ &c. is first obtained. By this motion the value of K which characterised the point $x-\delta x$ &c. is given to x, y, z; that is, K is altered by the amount

$$\delta K = -\partial K/\partial x \,.\, dx - \text{ \&c.},$$

and ϕ at x, y, z in the same way becomes altered by

$$\partial\phi = -\partial\phi/\partial x\, dx - \text{ \&c.}$$

At the surfaces of the conducting-bodies which form the surface-limits of the volume integration of W the value of ϕ at $\bar{x}$, $\bar{y}$, $\bar{z}$ becomes that of the point $\bar{x}-\delta x$, &c. But $\bar{x}$, $\bar{y}$, $\bar{z}$ have become $\bar{x}+\delta x$, &c.; so that ϕ at the surface comes back to its old values. The conductors therefore remain at constant potential. We have then, putting R^2 for $(\partial\phi/\partial x)^2+$&c., and $d\Omega$ for an element of volume,

$$\delta W = \Sigma\, \delta \iiint \frac{K}{8\pi} R^2 d\Omega.$$

After reduction, this becomes

$$\delta W = -\Sigma \iiint \frac{R^2}{8\pi}\left(\frac{\partial K}{\partial x}\delta x + \&c.\right) d\Omega$$
$$+\Sigma \iint \frac{K}{4\pi}\frac{\partial \phi}{\partial u}\left(\frac{\partial \phi}{\partial x}\delta x + \&c.\right) dS$$
$$-\Sigma \iint \frac{K}{4\pi} R^2 \{\cos(nx)\, dx + \&c.\}\, dS,$$

where n is the normal at the surface-element dS. This gives, by consideration of the coefficients of δx, δy, δz, the stresses per unit-volume for the medium

$$X = -\frac{R^2}{8\pi}\frac{\partial K}{\partial x}, \quad Y = \&c.\ \&c.,$$

and the stresses per unit-area on an element of the surface of the conductors,

$$X = \frac{K}{4\pi}\frac{\partial \phi}{\partial u}\cdot\frac{\partial \phi}{\partial x} - \frac{K}{8\pi}R^2\cos(nx), \ \&c.$$

The resultant force on the surface is thus

$$K/8\pi(\partial\phi/\partial n)^2,$$

and is directed from the element towards the medium. At the surface of separation of two media the resultant force F, the normal component F_n, and tangential component F_s in the medium to which the quantity K belongs, is given by

$$F = \frac{K}{8\pi}R^2, \quad F_n = \frac{K}{8\pi}\left\{\left(\frac{\partial \phi}{\partial n} - \tfrac{1}{2}R^2\right)\right\}, \quad F_s = \frac{K}{4\pi}\frac{\partial \phi}{\partial n}\frac{\partial \phi}{\partial \rho},$$

with similar formulas for the other medium with the quantities K', n' substituted for K, n. Using the ordinary surface-conditions,

$$K\,\partial\phi/\partial n - K'\,\partial\phi'/\partial n' = 0, \quad R'^2 - R^2 = (\partial\phi'/\partial n')^2 - (\partial\phi/\partial n)^2,$$

the tangential stresses F_s, F_s' are found to be equal, and the resultant of F, F' is a normal to the element of surface, and of amount

$$F_n - F_n' = \frac{K'-K}{8\pi}\left\{R^2 + \frac{K-K'}{K'}\left(\frac{\partial\phi}{\partial u}\right)^2\right\}.$$

A similar formula holds when one of the media is simply ether. By a transformation, in which δW is expressed wholly in volume-integrals, the well-known Maxwellian system of stress in the interior of the dielectric is arrived at.

The author by similar processes, introducing the special hypotheses, obtains v. Helmholtz's and Kirchhoff's systems of stress in

the medium. These special hypotheses are, respectively, that the value of K is affected (1) by a change of density resulting from the space-variation of the displacements δx, δy, δz; and (2) the alteration of dimensions of an element of the dielectric along and at right angles to the lines of force. A. Gy.

---

625. *Relation of the (Electric) Equipotential Lines to Magnetic Lines of Force.* **L. Boltzmann.** (Wied. Ann. 51. pp. 550–558, 1894.)—This paper is a discussion of views put forward by Prof. E. Lommel (Wied. Ann. 48. 49. 50. 1893), in which the equipotential lines in a current-sheet were shown to be apparently coincident with the lines of force, and are made visible by strewing iron filings upon the plate. Boltzmann states that it might appear that, according to Maxwell's theory, the magnetic force at any point of a body carrying currents is conditioned only by what is going on in the body in the immediate neighbourhood, and that therefore it might be concluded that the lines of magnetic force at any place depend wholly upon the tubes of flow at the point considered. This, however, he points out would be an error, since the currents at and near the point considered only lead to a differential equation for the magnetic force, and that the equipotential lines and the lines of magnetic force depend upon boundary conditions which are essentially different in the two cases. He considers a current-sheet of which the tangent-plane at the point considered is the plane of x, y, and the direction of flow at the same point in the direction of x. From the ordinary equations,

$$4\pi(u, v, w) = \left(\frac{\partial\gamma}{\partial y} - \frac{\partial\beta}{\partial z}, \frac{\partial\alpha}{\partial z} - \frac{\partial\gamma}{\partial x}, \frac{\partial\beta}{\partial x} - \frac{\partial\alpha}{\partial y}\right),$$

where α, β, γ are the components of magnetic induction, he shows that, since α, β, γ (the plate being thin) vary very much more quickly in the direction of z than in any direction in the tangent-plane, and v and w are each zero,

$$\beta_0 - \beta_1 = 4\pi \int u\, dz, \qquad \alpha_0 = \alpha_1, \qquad \gamma_0 = \gamma_1,$$

where the suffixes 0, 1 refer to the two sides of the plate. Thus there is a difference $\beta_0 - \beta_1$ on the two sides of the plate, which is at right angles to the direction of flow and in the tangent-plane, and is therefore coincident in direction with the equipotential lines for the current. If then the remaining force-component of magnetic force be in the direction of z, the resultant magnetic force will be at right angles to the lines of flow, and the component in the plate will be at each point along the equipotential line there. This condition may be taken to be fulfilled when the plate is plane.

The author then proceeds to show that if a surface or a body in which a system of currents exists have a plane of symmetry with regard to which also the stream-lines are symmetrical, this plane must itself be a current-sheet, and the lines of magnetic force will be at right angles to the plane, and refers to the case of surfaces

and solids symmetrical about an axis, and carrying currents the stream-lines of which are meridian curves along the surface or coaxial surfaces, and the lines of magnetic force are parallel circles in planes perpendicular to the axis. Hence he concludes that Prof. Lommel's proposition as to the coincidence of lines of magnetic force and equipotential lines cannot be upheld.

The remainder of the paper is devoted to a criticism of Prof. Lommel's views, contained in the papers referred to, as to the origin of the Hall phenomenon. A. Gy.

---

626. *New kind of Rays in Electric Sparks.* **E. Wiedemann.** (Zschr. f. Elektrochemie, 8. pp. 159–162, 1895.)—Many substances glow when warmed, but lose this property after being once heated. They regain it, however, if an electric spark passes in their neighbourhood. The author investigates the nature of the rays that give rise to this effect. A plate of a substance permeable to ordinary light but not to the ultra-violet rays stops the effect. In order to find whether it is the ultra-violet rays or not that restore the power of glowing, a layer of the substance rendered insensitive by heating is half covered by a quartz or fluorspar plate, and a series of sparks passed near it. Most substances show no difference between the covered and uncovered parts, but calcium sulphate containing a trace of manganese sulphate, and a few similar mixtures, are found to be rendered sensitive where they are uncovered, but to remain insensitive where they are covered. Hence, since the fluorite plate does not cut off the ultra-violet rays it cannot be these that give the effect. The author concludes that the spark gives out a new kind of radiation to which fluorite is opaque. Similar results are obtained when the discharge through a gas at low pressure is used instead of a series of sparks. The author is still investigating the properties of these rays and intends to publish an account of his experiments in Wiedemann's Annalen. J. W. C.

---

627. *Static and Dynamic Discharge-Potentials.* **R. Swyngedauw.** (C. R. 121. pp. 118–121, 1895.)—A spark can be made to pass between two conductors either by joining them to the poles of an electrostatic machine, or by putting them in connexion with a wire along which a discharge passes. It has generally been assumed that the same difference of potential between the conductors causes the spark to pass in the two cases, but M. Jaumann has recently called this in question (Sitz. Ber. Wien. Akad. 1888, p. 765). The author uses two pairs of conductors, E_1 E_2 and N_1 N_2, E N_1 being joined by a wire, as also are E_2 N_2. The distances are adjusted so that when E_1 and N_1 are joined to one pole of a Herz machine and E_2 N_2 to the other, the spark just passes at say E_1 E_2, and not at N_1 N_2. If, now, the conductors are charged dynamically by placing them in a circuit containing a condenser and a coil of high self-induction, the spark still passes at E_1 E_2 by preference. Similarly, if in the first case

it passes at N_1 N_2, it does so also in the second case, this being so whatever the forms of the conductors or however near the spark is to passing equally easily at both gaps. It is hence concluded that the above proposition is probably true. J. W. C.

628. *Vibrations of a Tuning-Fork in a Magnetic Field.* **Maurain.** (C. R. 121. pp. 248–250, 1895.)—With the axis and plane of vibration of the tuning-fork parallel to the magnetic field, the number of vibrations diminished 3·8 per cent. when the field was strengthened up to 6350 C.G.S. units. With the axis and the plane of vibration perpendicular to the field, the pitch rose 0·75 per cent. with a field of 6350 units. With the axis parallel to the field, the pitch rose 0·38 per cent. for a field of 1090 units. A number of different results for different strengths of field are given in the paper. In the first set of experiments, where the variations were greatest, a well-marked effect of hysteresis was observed, the lowering of the pitch for the same field was greater with a falling magnetising current than with a rising one. When the vibrations are deadened so much more rapidly when the field is stronger, the deadening is due to the Foucault currents, which tend to oppose the movement. A. P. T.

629. *Conductivity of Permanganic Acid.* **J. M. Lovén.** (Zschr. phys. Chem. 17. pp. 374–376, 1895.)—The author published four years ago a series of measurements of the conductivity of permanganic acid. These values are higher than those recently published by Francke (Abstract 464). To obtain the high values it is necessary to use electrodes with very little platinum black, as this finely divided metal decomposes the permanganic acid. S. S.

630. *Electric Constants of Water.* **G. Gouré de Villemontée.** (J. Phys. 4. pp. 293–301, 1895.)—The article is to a large extent a summary and criticism of work done on the difference of potential at the contact of liquids with metals since the time of Volta. Taking special regard to water, the experiments of the author show the important influence of impurities due to the vessel which holds the water, the immersion of the metal experimented with, &c. A. Gs.

631. *Electromotive Force of Clark, Gouy, and Daniell Cells.* **C. Limb.** (C. R. 121. pp. 199–200, 1895.)—The method for measuring the absolute value of the E.M.F. of the cells is that described by the author to the Academy, 28th May, 1894. It gives the following values at 0° C. :—

Clark (H form)	1·4535	}
Gouy (Journ. de Phys. 1888)..	1·3928	⁀ true volts.
Daniell, Fleming's type.....	1·0943	}

Lord Rayleigh found in 1884 the number 1·4527 true volts at 0° for the E.M.F. of a Clark. S. S.

[Recent measurements, 1892, by Mr. Glazebrook and the abstractor gave 1·4342 true volts at 15° for a Board of Trade pattern Clark, and reducing this to 0° C. with the coefficient ·00076 found by the same authors, the result 1·4505 is obtained. Now the H form of cell is usually lower than the Board of Trade pattern by about ·0004 volt, and this would require the H pattern to have an E.M.F. of 1·4501 true volts at 0°, if it is assumed that the temperature coefficients of the two patterns are the same. The result of C. Limb is ·0031 volt higher than this. S. S.]

---

632. *Recent Photographs of Lightning.* **N. Piltschikoff.** (C. R. 121. pp. 250–251, 1895.)—The author names three types of flash—"band-lightning, tube-lightning, and waterspout-lightning" (éclair-tube, éclair-bande, éclair-trombe). He finds the first two in all storms, the third once only. From the measured width of the band-lightning on photographs, and the computed distance, he estimates the actual widths at from 12 to 62 metres. (*Cf.* B. A. Report, 1891, pp. 136–137.) A. P. T.

---

633. *Seat of the Electromotive Force in a Voltaic Cell.* **W. Ostwald.** (Zschr Elektrochemie, No. 7. pp. 123–132, 1895.)—A lecture on the history and modern views of the seat of the E.M.F. in a cell. S. S.

---

634. *Static and Dynamic Potentials.* **R. Swyngedauw.** (C. R. 121. pp. 195–198, 1895.)—This paper is a continuation of that described in Abstract no. 627. According to Jaumann the explosive potential is lower the more rapidly a conductor is charged. To test this the author connects a pair of conductors with a condenser, which he charges slowly till a spark passes, and observes the difference of potential necessary to cause the discharge. Next he charges the condenser again up to very nearly the same potential, and by allowing a spark to pass in a circuit connected with the first he abstracts enough electricity to charge a second condenser of small capacity, thus causing a small but rapid change in the difference of potential between the two conductors. He finds that this never causes a discharge to pass, provided the conductors are screened from ultra-violet light, and hence concludes that Jaumann is wrong. Ultra-violet light has a greater effect in lowering the dynamic than the static discharge potential, and the author thinks that Jaumann was misled through neglecting to screen his conductors. J. W. C.

---

635. *Residual Charge.* **A. S. Dunstan.** (El. World, 26. pp. 3–4, 1895.)—The rate of growth of residual charge for a mica condenser is measured by an electrometer, in conjunction with a Duboscq chronograph. The condenser is first charged for a

definite time, and then discharged for a definite time, after which, at successive time-intervals, the potential difference at the condenser terminals is noted. Curves are given showing the way in which the residual charge varies with the E.M.F. of the charging battery; they exhibit a general similarity of forms with all E.M.F.s, but the slopes are steepest in those curves which correspond to the higher E.M.F.s of charging. This means that the residual charge which follows upon a charge of high E.M.F. attains a given fraction of its maximum value in a shorter time than the residual charge following upon a lower E.M.F. The maximum value is directly proportional to the E.M.F. of the charging battery; this agrees with the result found by Hopkinson for glass. The effect of reversals was examined as follows:—For a determined number of seconds the condenser was charged in a certain direction, called "negative," it was then short-circuited for a known time, after which it was given a "positive" charge of definite duration; it was then again short-circuited for a known time, and, finally, the rate of growth of the residual charge was observed. It is found that although the total residual charge is diminished by the "negative" preliminary charge, the rate of development of the residuum is increased by the process. R. A.

---

636. *Remarks on Mack's Article on the Double Refraction of Electrical Rays.* **W. von Bezold.** (Wied. Ann. 54. pp. 752–754, 1895.)—In his paper Mack mentions the experiments of Starkl on the different heat conductivities of wood in directions parallel and perpendicular to the fibre as having given rise to his research. The author in 1871 discovered a similar property of wood for electrical rays. The Lichtenberg figures formed on a plate of wood cut parallel to the fibre, were found to be elliptical, as they are on doubly refracting crystals. These figures, however, have far less eccentricity than those produced by Sénarmont's method; but while the latter have their major axes in the direction of the fibre, those of the Lichtenberg figures are perpendicular to this direction. The author suggests the continuance of the experiments with a view to elucidating these peculiarities. He found the Lichtenberg figures were best produced by sprinkling lycopodium powder on the polished plates, and passing a discharge directly from an influence-machine (without condensers) through them. The double refraction of electrical rays may be shown otherwise than with wood. A vulcanite plate will give ellipses, if rendered anisotropic by sticking narrow parallel strips of tinfoil on the under side: the eccentricity is increased by connecting the ends of the strips together along the edges. Probably any series of conductors, or even dielectrics with a different constant, similarly placed in any dielectric would form a doubly refracting body for electrical waves of suitable length, and by an appropriate arrangement a circularly polarising body could no doubt be produced. G. H. B.

---

637. *Theory of Dispersion.* **R. Reiff.** (Wied. Ann. 55. pp. 82–94, 1895.)—Helmholtz assumes that the rapid electric oscillations which constitute light set in vibration the atoms (ions) of the medium through which they pass, such vibration being opposed by a frictional resistance. The author discusses this theory, and extends it so as to include the case of ions possessing any finite number of periods of vibration. He then shows that it furnishes a relation between the greatest length of ether-wave to which any ion can respond and the electric charge of the ion. In the cases of quartz and fluorite the theory gives values which are not inconsistent with those obtained by experiment. J. L. H.

---

638. *Mean Values of the Magnetic Elements of the Earth.* **A. de Tillo.** (C. R. 121. pp. 97–100, 1895.)—The author finds that the mean values of the magnetic elements taken all round a parallel of latitude are such as would be given by a magnet within the centre of the earth placed with its axis coinciding with the axis of rotation of the earth. If ϕ is the latitude, H the horizontal, and V the vertical component of the earth's magnetism, T the total force, P the magnetic potential, and θ the dip,

$$H = H_0 \cos\phi$$
$$P = H_0 \sin\phi$$
$$V = 2P$$
$$\tan\theta = 2\tan\phi$$
$$T = \frac{H}{\cos\theta} = \frac{V}{\sin\phi}.$$

The value for the constant H_0, which gives values agreeing best with the true values, is 0·328 C.G.S. See also Abstract 182, p. 84. W. W.

CHEMICAL PHYSICS.

639. *Solubility of some Organic Compounds in Carbon Bisulphide at Low Temperatures.* **Arctowski.** (C. R. 121. pp. 123–125, 1895.)—According to Étard, the curves of solubility and temperature for substances dissolved in liquids other than water, are hyperbolas passing through the points of fusion of the solvent and the dissolved substance respectively. Étard considers the solubility to be zero at the former and infinite at the latter of these temperatures: but Alexejeff has shown that the substances cease to be miscible in all proportions at a temperature which is not the melting-point of the less fusible one. The author has investigated the conditions of zero-solubility for the case of carbon bisulphide. He finds that at its melting-point (−115° C.) this liquid can dissolve appreciable quantities of many substances both organic and inorganic. The solubility-curves of triphenylmethane, naphthalene, and diphenylamine were plotted for temperatures between −80° C. and −117° C.; these show no tendency to intersect the line of temperature, but apparently approach it asymptotically. It is therefore concluded that substances possess the power of diffusion at temperatures below their freezing-points, just as they are able to give off vapour at such temperatures. It follows that the temperature of fusion is not a point of special importance in the solubility-curve. J. L. H.

---

640. *Valency of Mercury in Solutions of its Salts. Part I.* **W. Bolton.** (Zschr. f. Elektrochemie, 5. pp. 73–79, 1895.)—The weight of mercury deposited by a measured quantity of electricity gives the valency of the mercury in the solution electrolysed. The author employed a mercury-voltameter, suggested by Ostwald, to measure the current. It consists of two glass cups about 1 cm. wide in a solution of $\frac{1}{10}$ normal mercurous nitrate, in which the metal is absolutely univalent. The mercury is dried after use by filter-paper and by running it along a trough of filter-paper The voltameter appears to be reliable and handy, on account of the high atomic weight of the metal, and the facility of purifying it; with a moderate current 5 or 10 minutes is sufficient to deposit a weighable amount, and either anode or cathode can be weighed. Such a voltameter was put in series with a similar vessel containing normal potassium iodide with a variable amount of mercuric iodide. It was found that when the latter salt was of $\frac{1}{24}$ or more the strength required to form the complex K_2HgI_4, it was strictly divalent; but in weaker solutions less mercury is deposited: with concentration $\frac{1}{384}$ the weight of mercury in the experimental cell was only 1·153 that in the voltameter. Weaker solutions give off hydrogen. The potential differences between the electrodes and the solution were measured by means of Ostwald's normal elec-

trode; for the stronger solutions these are constant; while as the dilution proceeds the polarisation at the anode diminishes somewhat, and that at the cathode increases considerably. This is in accordance with Ostwald's view that the polarization depends only on the number of ions of the same kind as the electrode itself; the number is, of course, increased at the anode by the passage of a current, and decreased at the cathode. But disturbance of the normal distribution only becomes appreciable when the whole number in solution is small, and when the number is sufficiently reduced, less energy is required to discharge one of the numerous potassium (or practically hydrogen) ions than a mercury one; so hydrogen is evolved at the cathode. R. A. L.

---

641. *Volumes of Salts in Aqueous Solutions.* **L. de Boisbaudran.** (C. R. 121. pp. 100–102, 1895.)—Certain ammonium salts, notably the chloride, undergo dilatation when dissolved in water at ordinary temperatures, thus forming exceptions to the general rule that the volume of a solution is smaller than those of its constituents. The author suggests that the ammonium salts occupy the highest place in a continuous series at the lower end of which are those salts which give rise to the greatest contraction. Change of volume during solution depends on (1) the dilatation or contraction which would take place if the salt were fused at the temperature of the experiment without decomposition, (2) the contraction arising from the combination of the salt with the solvent, which increases with increasing dilution or with decrease of temperature. At 15° C. ammonium chloride always expands when dissolved in water; but at 0° C. a slight contraction takes place in dilute solutions. Similarly hyposulphite of soda contracts enormously at 15° C. in dilute solutions, but it expands in concentrated solutions. The author gives curves showing the behaviour of ammonium chloride, sodium acetate, and sodium hyposulphite respectively. J. L. H.

---

642. *Atomic Weight and Valency.* **C. J. Reed.** (J. Frank. Inst. 835. pp. 68–76, 1895.)—Oxygen is taken as an arbitrary standard of valency, by assuming that in combination it is always an electro-negative dyad. The valency of other elements is determined in any particular compound by further assuming that the algebraic sum of the affinities in a molecule is always zero. It is shown that a remarkable relation exists between the electrochemical affinity and the atomic weight of an element, the valency being an equi-crescent rotary, or helical function of the atomic weight. Points are located in a plane for each of the elements, abscissæ being taken proportional to atomic weight and ordinates proportional to valency. Electro-positive valency is measured upwards, and electro-negative valency downwards. Most of the elements, especially those of low atomic weight, fall on a peculiar series of double, equidistant parallel lines, separated alternately by distances of one and sixteen units of atomic weight. But this

regularity is not maintained among the elements of higher atomic weight, and the elements from Ru to Te exhibit a diagonal movement from one pair of parallels to the next. By bending the plane into a cylinder, having a circumference equal to eight units of valency, the parallels are all united into a double helix. The axis of abscissæ forms an element of the surface of the cylinder, and the axis of ordinates becomes a circle of the cylinder; valency, now measured in angular measure, is directly proportional to atomic weight. It is remarkable that all elements which exhibit both electro-positive and electro-negative affinities, have a well-defined positive and a well-defined negative valency, which differ by 8 units. The double helix, which may be called the locus of elements, cuts the axis of atomic weights at fifteen points. This suggests that there should be a group of fifteen elements having a valancy of 0 or 8. The members of this group which are most likely to be found in terrestrial matter are those having the atomic weights 4, 20, 36, 52, 84, 132, and 196. The author states generally the properties which these elements may be expected to possess. He assumes that argon fills one of the vacant places with an atomic weight of 20 (in fact the paper is entitled "Reasons for Predicting the Existence of Argon"). D. E. J.

643. *Combination of Argon with Carbon Bisulphide.* **Berthelot.** (C. R. 120. pp. 1316-1319, 1895.)—The electric discharge determines a more complete combination of argon with carbon bisulphide than with benzene vapour. The absorption is accompanied by a fluorescence visible in daylight. After the absorption, mercury sulphocyanide was proved to be absent from the product. On heating the product, the argon is liberated, whereas in the same experiment, using nitrogen, no gas was evolved. That argon is regenerated from its combination with the carbon bisulphide was proved by examining spectroscopically the fluorescent phenomena of the liberated gas when sparked in the presence of benzene. S. R.

644. *Constituents of Clèveite Gas.* **C. Runge** and **F. Paschen.** (Berl. Ber. 34. pp. 759–763, 1895.)—The authors have prepared better Geissler tubes containing fewer impurities, and giving the lines of the gas itself with greater brilliancy. They have investigated with the bolometer the ultra-red part of the spectrum up to 10 μ, and have also succeeded in making a more satisfactory comparison of other lines of the spectrum. A further investigation of the "series" of lines (see Abstract no. 569, p. 345) contained in the spectrum leads them to conclude that there are two separate systems of series; these they attribute to two separate constituents, helium being the constituent which gives the system to which the yellow line D_3 belongs. This is confirmed by the fact that those lines of the clèveite spectrum which are always observed in the spectrum of the solar chromosphere belong all to one of the two

systems—viz. the helium system; whereas those lines of the second system which have hitherto been observed in the chromosphere make their appearance, according to Young, much less frequently. Chemical considerations suggest that helium is the heavier of the two constituents and has an atomic weight of about 5, the lighter constituent having an atomic weight of about 3. In filling one of the tubes the gas had to pass through an asbestos plug. On first opening the stopcock the tube at first gave out a green light, and the line 5016 was seen to be as bright as the yellow line. The colour gradually changed to yellow, and the line 5876 (D_3) became much stronger than 5016. This entirely agrees with the supposition that the constituent of which 5016 forms the brightest line is lighter than helium, for the lighter constituent would first diffuse through the plug. D. E. J.

CLARENDON PRESS LIST.

By Prof. W. W. Skeat, Litt.D.

In Six Vols. Demy 8vo, with Portrait and Facsimiles. £4 16*s.*

THE COMPLETE WORKS OF GEOFFREY CHAUCER. Edited from numerous MSS.

In Two Vols. Demy 8vo, uniform with the above. £1 11*s.* 6*d.*

PIERS THE PLOWMAN. Edited from numerous Manuscripts, with Preface, Notes, and Glossary.

In One Vol. Crown 8vo, Cloth. 7*s.* 6*d.*

THE STUDENT'S CHAUCER. Being a Complete Edition of his Works. Edited from numerous Manuscripts, with Introduction and Glossary.

"If the Library Edition of Prof. Skeat's 'Chaucer' is one which no gentleman's library should be without, the Student's Edition is one which every lover of literature should acquire."—*National Observer.*

THE OXFORD ENGLISH DICTIONARY.

New Parts recently published. 4to. Paper Covers.

A NEW ENGLISH DICTIONARY on HISTORICAL PRINCIPLES. Founded mainly on the Materials collected by the Philological Society.

D—Deceit. Edited by Dr. MURRAY. 3*s.* 6*d.*
Deceit-Deject. Edited by Dr. MURRAY. 2*s.* 6*d.*
F—Fang. Edited by HENRY BRADLEY, M.A. 2*s.* 6*d.*
Fanged-Fee. Edited by HENRY BRADLEY, M.A. 2*s.* 6*d.*

☞ The Delegates of the Press have arranged for the punctual issue of the letters D and F in Quarterly Sections. One Section at least, consisting of 64 pages, will be published quarterly at Half-a-crown.

6 vols. Medium 8vo, half-bound. £3 3*s.*

BOSWELL'S LIFE OF JOHNSON. With the Journal of a Tour to the Hebrides. Edited by G. BIRKBECK HILL, D.C.L., Pembroke College.

2 vols. Medium 8vo, half-roan. 28*s.*

LETTERS OF SAMUEL JOHNSON, LL.D. Collected and edited by G. BIRKBECK HILL, D.C.L.

FULL CLARENDON PRESS CATALOGUES POST FREE ON APPLICATION.

London:

HENRY FROWDE, Clarendon Press Warehouse, Amen Corner, E.C.

OPTICAL AND SCIENTIFIC INSTRUMENTS.

Spectrometers, Spectroscopes, Goniometers, Cathetometers, Optical Benches, &c., &c. Instruments for special purposes constructed to Clients' own designs. *Prices moderate. Price List free.*

W. WILSON (formerly Foreman at Messrs. Elliott Bros.),
56 CROGSLAND ROAD, CHALK FARM, N.W.

PUBLICATIONS OF THE PHYSICAL SOCIETY.

THE SCIENTIFIC PAPERS

OF THE LATE

SIR CHARLES WHEATSTONE, F.R.S.

Demy 8vo, cloth. Price 15s.; to Members of the Society, 7s. 6d.

Uniform with the above.

THE SCIENTIFIC PAPERS

OF

JAMES PRESCOTT JOULE, D.C.L., F.R.S.

Vol. I. 4 Plates and Portrait, price £1; to Members of the Society, 10*s.*

Vol. II. 3 Plates, price 12*s.*; to Members of the Society, 6*s.*

PHYSICAL MEMOIRS.

PART I.—VON HELMHOLTZ, On the Chemical Relations of Electrical Currents. Pp. 110. *Price 4s.; to Members of the Society, 3s.*

PART II.—HITTORF, On the Conduction of Electricity in Gases; PULUJ, On Radiant Electrode Matter. Pp. 222. *Price 7s. 6d.; to Members, 5s. 8d.*

PART III.—VAN DER WAALS, On the Continuity of the Liquid and Gaseous States of Matter. Pp. 164. *Price 6s.; to Members, 4s. 6d.*

PROCEEDINGS.

To Members of the Society only, at the following prices:—

Vols. I.–IV. 2 vols., cloth, 25*s.*, unbound 23*s.*

Vols. V. & VI. 1 vol., cloth, 13*s.*, unbound 11*s.*

Vols. VII. & VIII. 1 vol., cloth, 13*s.*, unbound 11*s.*

Vols. IX. & X. 1 vol., cloth, 16*s.*, unbound 14*s.*

Vols. XI. & XII. 1 vol., cloth, 16*s.*, unbound 14*s.*

These prices do not include carriage.

APPLICATIONS FOR THESE VOLS. MUST BE SENT DIRECT TO

TAYLOR and FRANCIS, Red Lion Court, Fleet Street, E.C.

INDEX TO ABSTRACTS.

GENERAL PHYSICS.

Page

604. Physical Properties of Solid Carbonic Acid. *P. Villard* 363
605. Interpretation of Lunar Photographs. *Lœwy & P. Puiseux* 363
606. Solubility of Metals in Mercury. *Gouy* 364
607. Linkwork with Jointed Quadrilaterals. *N. Delaunay* 364
608. Kinetic Theory of Heavy Fluids. *L. Houllevigue* 365
609. Algebraical Machines. *L. Torres* 366
610. Laws of Friction. *P. Painlevé* 367
611. Osmotic Phenomena between Ether and Methyl Alcohol across various Membranes. *F. M. Raoult* 367
612. Muscular Energy of Positive and Negative Work. *A. Chauveau* ... 367
613. Maxwell's Theory of Movement of Pure Ether. *H. v. Helmholtz* ... 368

LIGHT.

614. Comparison of the Spectra of the Gas from Clèveite and of the Solar Atmosphere. *H. Deslandres* 371
615. Colour Photography by Absorption-Colours, and Mechanical Colour-Selection in Nature. *O. Wiener* 371
616. Theory of the Perception of Colours. *G. Darzens* 377
617. Photography in Natural Colours. *R. Neuhass* 377
618. Colour Perception. *H. W. Vogel* 378

HEAT.

619. Mercury Thermometer Corrections 380
620. Mirage Effects in Natterer's Tubes. *P. Villard* 380

SOUND.

621. Velocity of Sound. *Aignan & Chabot* 381
622. Two Graphic Methods of Counting Beats, and a Microphonic Capsule. *F. Campanile* 381

[*Continued over-leaf.*

ELECTRICITY.

Page

623. Radiation of Electromagnetic Energy in Space. *K. Birkeland* 382
624. Ponderelectromotive Forces due to Variations of Electrostatic Energy. *N. Schiller*..... 383
625. Relation of the (Electric) Equipotential Lines to Magnetic Lines of Force. *L. Boltzmann* 385
626. New kind of Rays in Electric Sparks. *E. Wiedemann* 386
627. Static and Dynamic Discharge-Potentials. *R. Swyngedauw*..... 386
628. Vibrations of a Tuning-Fork in a Magnetic Field. *Maurain* 387
629. Conductivity of Permanganic Acid. *J. M. Lovén*..... 387
630. Electric Constants of Water. *G. Gouré de Villemontée*..... 387
631. Electromotive Force of Clark, Gouy, and Daniell Cells. *C. Limb* ... 387
632. Recent Photographs of Lightning. *N. Piltschikoff* 388
633. Seat of the Electromotive Force in a Voltaic Cell. *W. Ostwald* 388
634. Static and Dynamic Potentials. *R. Swyngedauw* 388
635. Residual Charge. *A. S. Dunstan* 388
636. Remarks on Mack's Article on the Double Refraction of Electrical Rays. *W. v. Bezold*..... 389
637. Theory of Dispersion. *R. Reiff* 390
638. Mean Values of the Magnetic Elements of the Earth. *A. de Tillo* ... 390

CHEMICAL PHYSICS.

639. Solubility of some Organic Compounds in Carbon Bisulphide at Low Temperatures. *Arctowski* 391
640. Valency of Mercury in Solutions of its Salts. Part I. *W. Bolton* ... 391
641. Volumes of Salts in Aqueous Solutions. *L. de Boisbaudran*..... 392
642. Atomic Weight and Valency. *C. J. Reed* 392
643. Combination of Argon with Carbon Bisulphide. *Berthelot* 393
644. Constituents of Clèveite Gas. *C. Runge & F. Paschen* 393